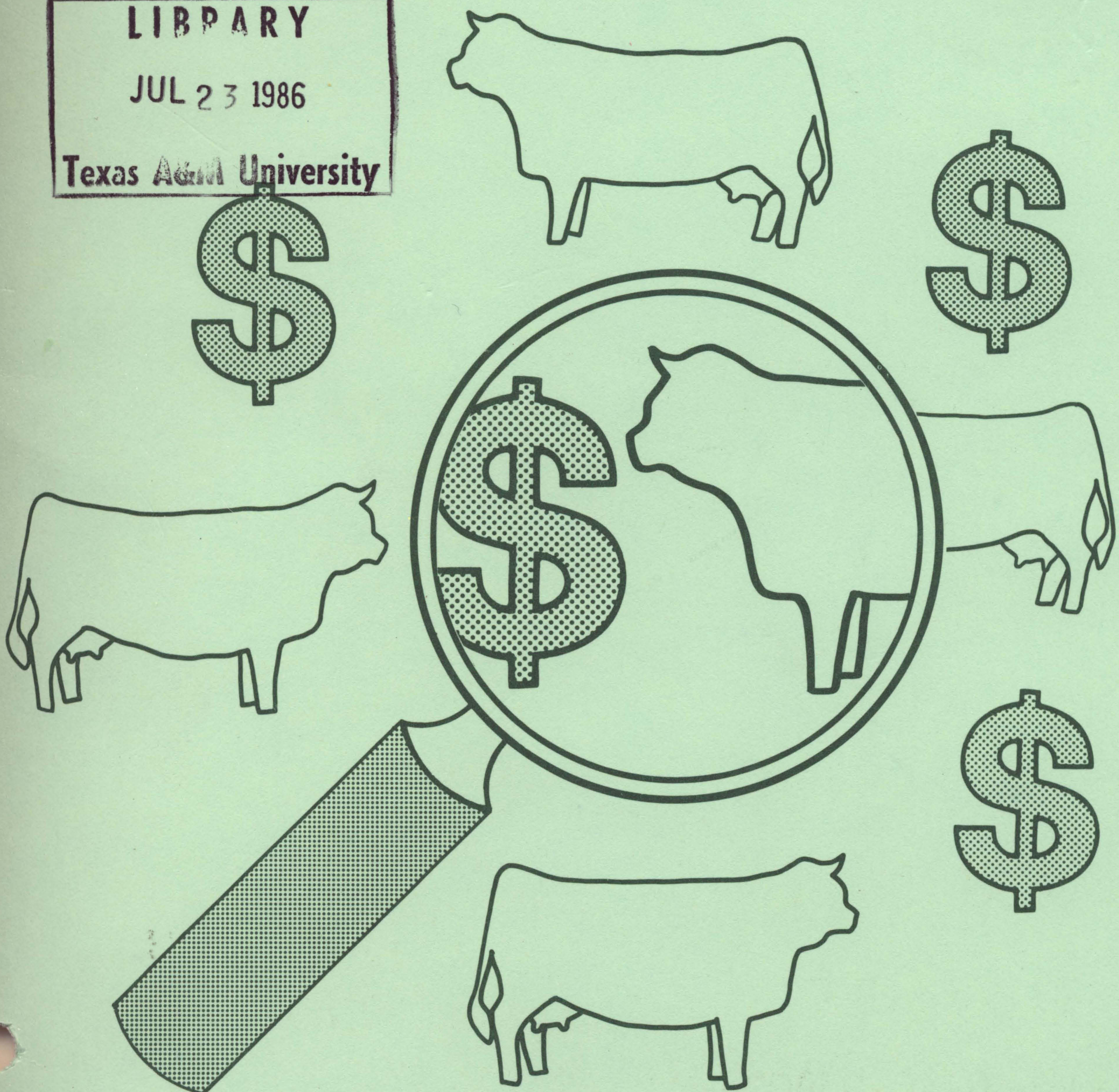
B-1534
April 1986

ECONOMIC AND EPIDEMIOLOGIC ANALYSIS OF U. S. BOVINE BRUCELLOSIS PROGRAMS



THE TEXAS AGRICULTURAL EXPERIMENT STATION/Neville P. Clarke, Director/The Texas A&M University System/College Station, Texas

Table of Contents

Preface

Details concerning the contract report, "Economic and Epidemiologic Analysis of U.S. Bovine Brucellosis Programs" consisting of Volumes I, II, and III are available from Veterinary Services, APHIS, U.S. Department of Agriculture, Hyattsville, Maryland, 20782. Volume I is the primary report; Volume II contains the epidemiological model, the computer program, and the input data; and Volume III contains the national epidemiological summaries of the nine programs simulated and regional summaries of the 1984 current program. These reports are also available from the Department of Agricultural Economics, Texas A&M University, College Station, Texas, 77843 as follows:

Volume I-Departmental Technical Report DTR86-1,
Volume II-Departmental Technical Report DTR86-2,
Volume III-Departmental Technical Report DTR86-3.

Economic and Epidemiologic Analysis of U.S. Bovine Brucellosis Programs

Authors

RAYMOND A. DIETRICH, Associate Professor
The Texas Agricultural Experiment Station
(Department of Agricultural Economics)

STEPHEN H. AMOSSON, Former Visiting Assistant Professor
The Texas Agricultural Experiment Station
(Department of Agricultural Economics)

RICHARD P. CRAWFORD, Professor
The Texas Agricultural Experiment Station
(Department of Veterinary Public Health)

Highlights

The Cooperative State-Federal Brucellosis Eradication Program, established in 1934, has been highly successful in reducing brucellosis infection in U.S. cattle herds. Reactor rates in U.S. adult cattle decreased from 11.5 percent in 1935 to a Market Cattle Identification reactor rate of 0.3 percent in 1984. Weaner calf and milk losses to producers decreased from $100 million in the 1940's to $32 million in 1983. Forty states, which were classified Class Free or Class A states in 1985, accounted for two-thirds of the U.S. cow population and 5 percent of the quarantined herds. At the same time, 10 states were classified Class B or Class C and contained one-third of the U.S. cow population and 95 percent of the U.S. quarantined cattle herds.

The purpose of this research was to analyze the economic and epidemiologic impact of specified alternative bovine brucellosis programs and to provide a benefit-cost analysis of these alternative brucellosis control and/or eradication strategies. These strategies and/or alternative brucellosis programs were examined in terms of their costs and benefits to society, consumers, producers, and related agricultural industries.

BRUSIM, a systems simulation model, was developed to measure the impact of various program components upon selected epidemiologic parameters and for determining associated costs and physical losses of brucellosis control/eradication programs given epidemiologic coefficients and economic criteria from 1976 through 2005. The United States was delineated into 16 regions based upon such factors as prevalence, producer characteristics, and cattle population. TECHSIM, an econometric model, was used for determining the total and net benefits accruing to society, consumers, producers, and related industries as a result of changes in beef and milk losses from alternative programs.

A base program and eight alternative bovine brucellosis programs were simulated for the contiguous 48 states from 1976 through 2005. The base program served as a basis for determining changes in physical losses and program expenditures for alternative programs. The eight alternative programs included a current program, two eradication programs, two programs with changes in program efficiencies in Class C regions, and three no state-federal program scenarios.

Four programs, the theoretical eradication program, the realistic eradication program, the base program with a 25 percent increase in efficiency in Class C regions, and the current program were highly effective in reducing brucellosis infection and physical losses from 1984 to 2005. Brucellosis infection and physical losses increased in all other programs simulated, especially the no state-federal program scenarios. Calfhood vaccination was highly effective in reducing infection and physical losses under the no program scenarios but the no state-federal program scenarios with and without calfhood vaccination were inferior to other alternative programs simulated.

The highest positive change in benefits to society, net change in benefits, and most acceptable benefit-cost ratios accrued from the eradication programs, followed by the base program with a 25 percent increase in efficiency in Class C regions, and the current program. The largest losses or negative changes in benefits to society, including generation of economically unacceptable benefit-cost ratios, accrued from the three no state-federal programs even with application of calfhood vaccination at relatively high levels.

The realistic eradication program was the most cost effective program since it ranked above other alternative programs, except the theoretical eradication program, in total benefits, net benefits, and benefit-cost ratios. The theoretical eradication program demonstrated that the present "state of the arts" within the U.S. bovine brucellosis program is highly capable of detecting sufficient numbers of infected herds for achieving eradication. Results showed that strict adherence to the requirements of the Uniform Methods and Rules was highly beneficial in terms of reducing infection and physical losses. Consumers were the major beneficiaries of investments in publicly funded bovine brucellosis programs which decreased losses and increased supplies of meat and milk.

Economic and Epidemiologic Analysis of U.S. Bovine Brucellosis Programs

Introduction

Bovine brucellosis, an infectious reproductive disease which can cause calf deaths, abortions, light calves, reduced milk production, and undulant fever in humans, is a major economic problem affecting the beef and dairy industries, consumers, and related agricultural industries. U.S. cattle producers incurred production losses exceeding $32 million from brucellosis in 1983 (Beal 1984). While such production losses are substantial, in some instances catastrophic, producers incur additional costs associated with testing and prevention practices. Consumers are impacted adversely through higher prices and smaller supplies of meat and milk. Related agricultural industries may incur losses from reductions in sales of products and services as the volume of cattle, meat, and milk declines.

The prevalence of brucellosis in the United States has decreased from an on-farm reactor rate of 11.5 percent in 1935-36 when the State-Federal Cooperative Brucellosis Eradication Program was launched on a national scale to a Market Cattle Identification (MCI) reactor rate of 0.97 percent in 1966 with a further decline to 0.3 percent in 1984 (Beal 1985). The State-Federal Cooperative Brucellosis Eradication Program has undergone numerous changes since its inception as discussed by Beal and Kryder 1977; Anderson et al. 1978; Jones 1979; and Amosson 1983. Some of the major events which have occurred with respect to the State-Federal Cooperative Brucellosis Program since 1935-36 are:

(1) Strain 19, a live vaccine, was introduced and used in 39 states in 1941.

(2) The first edition of Uniform Methods and Rules (UM&R) for the eradication of bovine brucellosis was adopted in 1947.

(3) The Brucellosis Ring Test (BRT) was adopted as a surveillance tool for dairy cattle in 1952. Through the use of BRT and follow-up cattle blood testing, suspicious herd milk samples declined from 26 percent in 1954 to 0.3 percent in 1976.

(4) In the fall of 1954, Congress appropriated additional funding to launch an all out effort to eradicate brucellosis. The basic thrust was area testing with quarantine and retesting of infected herds.

(5) The MCI program was developed as a surveillance tool during the early 1960's. This program was designed to test blood samples of cows slaughtered at packing plants (SPT). Some states have increased the MCI coverage to include all cows and eligible heifers passing through the marketing channels, which is often referred to as first point of concentration testing (FPC).

(6) Program officials made a decision to de-emphasize Strain 19 vaccination in 1967.

(7) FPC testing received added emphasis in high incidence states in 1974.

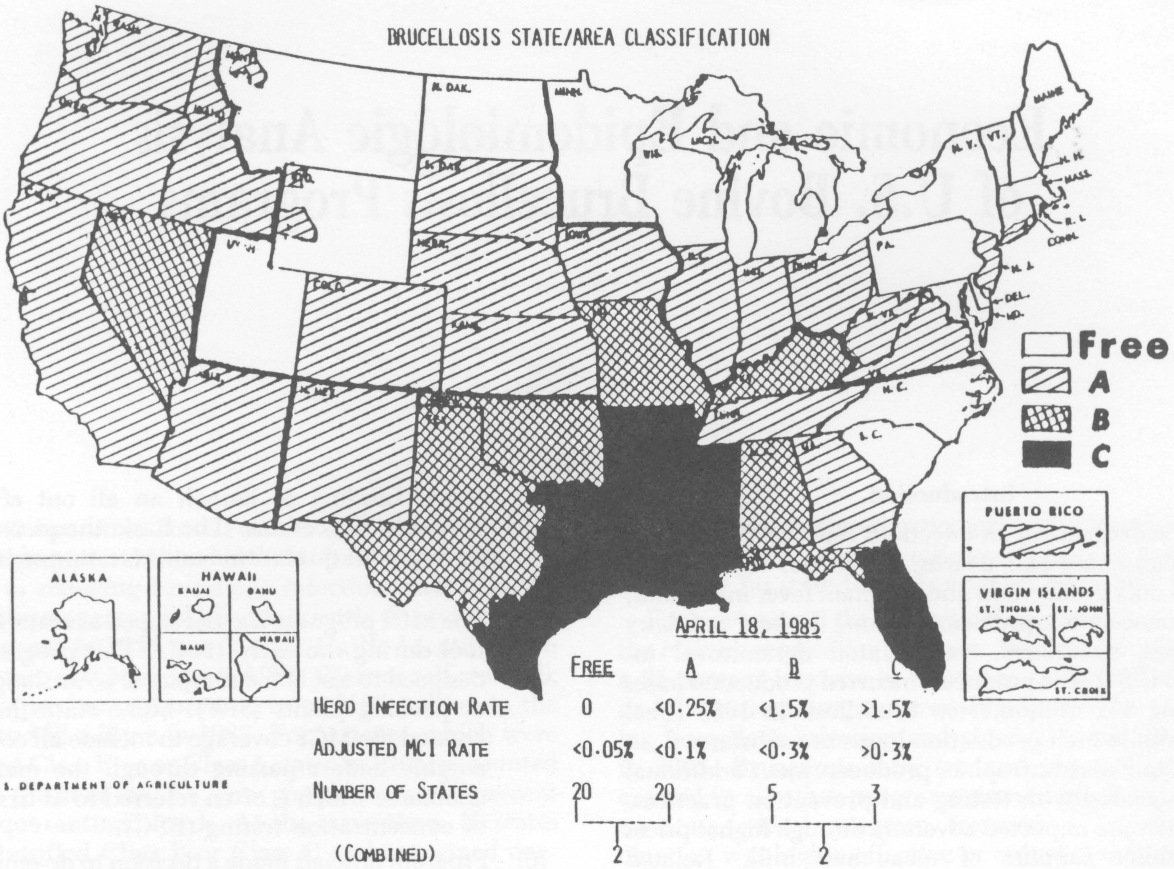
(8) As a result of increased infection in U.S. cattle herds, Strain 19 vaccination was once again emphasized by program officials in 1975.

(9) Congress appropriated additional federal funding in 1975 for brucellosis eradication with emphasis on herd depopulation, adjacent herd testing, and FPC testing.

(10) The U.S. Department of Agriculture appointed the National Brucellosis Technical Commission (NBTC) in 1976 to conduct an impartial study of the National Brucellosis Eradication Program. The NBTC study, completed in 1978, provided detailed findings and recommendations concerning program improvement to the Animal and Plant Health Inspection Service (APHIS), U.S. Department of Agriculture, and the United States Animal Health Association.

The distribution of bovine brucellosis infection in the United States as of April 1985 is broadly defined by the four level state classification system used by the U.S. Department of Agriculture (Figure 1). The Class Free states are primarily the northern-tier states-the Northeast, the Lake States, the Northern Plains, the Intermountain area, and the Atlantic Coast. Alaska and Hawaii are also Class Free states. The Class A states are

Figure 1. Brucellosis state/area classification, United States, 1985.



primarily in the West, the Northern Plains, the Corn Belt, and Atlantic Coast states. Class B and C states are primarily in the West and East South Central states and the Southeast.

The current distribution of cows in the United States by area classification reveals several important statistics. Class A states contained about 40 percent of the January 1, 1985 cow population, followed by Class Free states with 25 percent, Class B states with 20 percent, and Class C states with 15 percent (Table 1). Dairy cows comprised more than 52 percent of the total cows in Class Free states compared to 20 percent in Class A states, 8 percent in Class B states, and 7 percent in Class C states. Dairy cows in Class Free and Class A states comprised more than 87 percent of the U.S. dairy cow population in 1985. Although exceptions exist, these data reveal that the areas with greater concentrations of dairy herds, which routinely undergo a minimum of three to four BRT tests per year, also generally had the lowest levels of brucellosis infection. The net results are that states with relatively high concentrations of dairy cows, historically, have had to meet minimum health standards imposed by various cities and municipalities to qualify their products for sale within such areas. For example, the Chicago Board of Health stated in 1950 that within 5 years only milk from brucellosis-free herds would be acceptable for human consumption. Such market incentives encouraged predominant dairy states to institute animal health programs which permeated their cattle industry. However, there are exceptions in the predominant beef states as indicated by their current Class Free classification as well as the large number of beef states currently classified Class A (Table 1).

Another measure for determining the relative level of brucellosis infection is the infected herd rate per 1,000 herds at risk. States which had an infected herd rate of 5 or greater per 1,000 herds as of March 31, 1985, were led by Florida, Louisiana, Arkansas, Texas, Mississippi, and Oklahoma (Table 2). These six states accounted for more than 86 percent of the known infected herds in the United States as of March 1985. These states, plus Missouri, Kentucky, and Alabama, all reported 100 or more infected herds as of March 1985 and together accounted for almost 95 percent of the known infected herds in the United States.

The Problem

Bovine brucellosis reactors as identified by the MCI program decreased from 0.97 percent of the total cattle tested in 1966 to 0.31 percent in 1984. Further, initial follow-up tests of BRT suspicious herds which were

Table 1. Distribution of beef and dairy cows by state and bovine brucellosis area class, United States, April 1985

Area class[a] and state	Beef cows[b] 1,000 Head	Beef cows[b] Percent	Dairy cows[b] 1,000 Head	Dairy cows[b] Percent	Total cows 1,000 Head	Total cows Percent
Free:						
Alaska	3		1		4	
Connecticut	7		48		55	
Delaware	2		10		12	
Hawaii	82		12		94	
Maine	11		59		70	
Maryland	79		121		200	
Massachusetts	9		47		56	
Michigan	160		390		550	
Minnesota	420		890		1,310	
Montana[c]	1,513		27		1,540	
New Hampshire	5		31		36	
New York	88		942		1,030	
North Carolina	458		127		585	
North Dakota	964		97		1,061	
Pennsylvania	190		735		925	
Rhode Island	1		4		5	
South Carolina	272		47		319	
Utah	289		80		369	
Vermont	10		186		196	
Wisconsin	230		1,840		2,070	
Wyoming[c]	618		12		630	
Subtotal	5,411	15.3	5,706	52.8	11,117	24.1
Class A:						
Arizona	272		83		355	
California	1.011		974		1,985	
Colorado	855		75		930	
Georgia	771		118		889	
Idaho	538		162		700	
Illinois	615		225		840	
Indiana	439		197		636	
Iowa	1,305		345		1,650	
Kansas	1,512		108		1,620	
Class A continued.						
Nebraska	1,808		102		1,910	
New Jersey	16		39		55	
New Mexico	555		65		620	
Ohio	360		380		740	
Oregon	639		96		735	
South Dakota	1,627		161		1,788	
Tennessee	1,050		210		1,260	
Virginia	643		162		805	
Washington	398		211		609	
West Virginia	275		33		308	
Subtotal	14,689	41.5	3,746	34.6	18,435	39.9
Class B:						
Alabama	871		49		920	
Kentucky	1,038		232		1,270	
Missouri	2,000		225		2,225	
Nevada	307		18		325	
Oklahoma	1,993		107		2,100	
West Texas	2,100		141		2,241	
Subtotal	8,309	23.5	772	7.1	9,081	19.6
Class B&C						
Florida	1,161	3.3	164	1.5	1,325	2.9
Class C						
Arkansas	914		79		993	
Louisiana	670		95		765	
Mississippi	753		84		837	
East Texas	3,486		173		3,659	
Subtotal	5,823	16.4	431	4.0	6,254	13.5
United States	35,393	100.0	10,819	100.0	46,212	100.0

[a]Area classification as of April 16, 1985. Source: U.S. Department of Agriculture, APHIS, VS. Washington, D.C.

[b]January 1, 1985 beef and dairy cows that have calved. Source: U.S. Department of Agriculture. 1985. Cattle. Washington, D.C.

[c]Ninety percent or more of the cattle in Montana and Wyoming are in Class Free counties.

found to be infected declined from 1,653 in 1967 to 197 in 1984. The NBTC (1978) estimated that the combined economic losses to U.S. beef and dairy herds from brucellosis totaled $48 million in 1976 compared to $32 million in 1983 (Beal 1984).

While this data represents program progress in all dimensions, U.S. Department of Agriculture data indicates that bovine brucellosis infection was still present in 31 of the 50 states as of April 16, 1985. Given the wide variation in reactor rates between the non-Class Free states and the concentration of infection in nine states where 90 percent or more of the infection in the United States exists, it is essential that current and alternative bovine brucellosis programs are analyzed periodically to assure that the most economical and epidemiologically efficient programs are being utilized.

The purpose of this research was to analyze the economic and epidemiologic impact of specified alternative bovine brucellosis programs and to provide a benefit-cost analysis of these alternative brucellosis control and eradication strategies. These strategies and/or alternative brucellosis programs were examined in terms of their costs and benefits to the state and federal governments, the cattle industry, and society.

Source of Data

Data for this study were obtained from both primary and secondary sources. Much of the basic information and epidemiologic data for 1975-76 were obtained from the 1978 NBTC study. These data were supplemented and updated by information from the U.S. Department of Agriculture, U.S. Department of Commerce, V.S. APHIS Forms 4-33D and 4-35, and unpublished U.S. Department of Agriculture, VS, APHIS, program records as required.

A national survey of quarantined and non-quarantined Texas producers provided epidemiologic information concerning quarantine duration, number of tests, and initial and cumulative reactor rates with respect to herdsize structure. Data sources also included the expert judgement of NBTC personnel, Texas A&M University and state-federal epidemiologists, and state and federal program officials.

Epidemiologic and Econometric Models Employed

An epidemiologic simulation model and an econometric model were employed to analyze alternative U.S. bovine brucellosis programs (Figure 2). The epidemiologic model was designed to simulate selected herd and management characteristics, incidence and spread of infection, and the effects of prevention, control and/or eradication program components on the level of infection and physical losses, including associated producer and state-federal expenditures. The econometric model determines the economic impact of the change in physical losses of meat and milk, which are associated with alternative programs, on consumers, producers, and related industries.

The Epidemiologic Brucellosis Simulation Model

The epidemiologic brucellosis simulation model, BRUSIM, was redesigned and modified based upon previous research by Beal and Kryder (1977) and the NBTC (1978).[1] The Beal and Kryder (1977) model was modified by the NBTC to divide the United States into additional regions. The NBTC model also allowed affected herds to move into a quarantine status or undetected status, allowed the disease to spread between beef and dairy herds, allowed for early quarantine release, and included effects of the cattle cycle on replacement and cull rates.

The eight regions of the NBTC simulatin model were replaced by 16 regions in BRUSIM (Figure 3). Regions were specified on the basis of similarity with respect to such criteria as level of brucellosis infection, herd size distribution, method of operation, trading patterns, and effectiveness of brucellosis control.

Another major modification of the NBTC model in BRUSIM is the specification and separation of the effects of major program components. A series of equations representing MCI, FPC, and adjacent herd testing, secondary epidemiologic tracing, post-quarantine testing, and private or owner testing is contained in BRUSIM. Separation of the epidemiological model into major program components facilitates more realistic analysis concerning the contribution of such program components to the efficiency and costs of various programs analyzed. In addition, the three level vaccinal protection effectiveness function of the NBTC was modified to reflect a continuous vaccinal protection function in BRUSIM.

BRUSIM modifications from the NBTC simulation model also included expansion of the planning horizon to 30 years from 1976 to 2005, projected changes in cow inventories, and the effects of cyclical factors on replacement and cull rates. Expansion of the model planning horizon allows for potential lagged effects, which may accrue from certain program components, to be fully accounted for in the various programs simulated.

Table 2. Number of cattle operations, infected herds, and infected herd rate per 1,000 operations, by region, contiguous 48 states, March 31, 1985

Region	Operations with cattle[a]	Number of infected herds[b]	Infected herd rate per 1,000
NE-Lake[c]	398,120	18	0.045
Atlantic[d]	115,000	4	0.035
Alabama	42,000	108	2.571
Georgia	37,000	43	1.162
Kentucky	65,000	119	1.831
Mississippi	36,000	340	9.444
Tennessee	77,000	47	0.610
Florida	21,000	742	35.333
Arkansas	40,000	545	13.625
Louisiana	25,000	665	26.600
Oklahoma	66,000	352	5.333
West Texas[e]	57,225	135	2.358
East Texas[e]	94,650	1,492	15.763
N-Plains[f]	298,500	261	0.874
West[g]	138,600	43	0.310
California	35,000	26	0.743
Total	1,546,125	4,940	3.195

[a]Any place having one or more head on hand at any time during the year for 1984. Source: U.S. Department of Agriculture. 1985. Cattle. Washington, D.C.

[b]Infected herds as of March 31, 1985. Source: U.S. Department of Agriculture. 1985. Washington, D.C.

[c]Includes Connecticut, Delaware, Illinois, Indiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, and Wisconsin.

[d]Includes North Carolina, South Carolina, Virginia, and West Virginia.

[e]West Texas and East Texas correspond to Class B and Class C counties, respectively, as of March 31, 1985.

[f]Includes Iowa, Kansas, Missouri, Nebraska, North Dakota, and South Dakota.

[g]Includes Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming.

[1]For a detailed discussion of previous brucellosis simulation studies see the National Brucellosis Technical Commission Report (1978) and Amosson (1983).

Figure 2. Epidemidogic-economic systems flow.

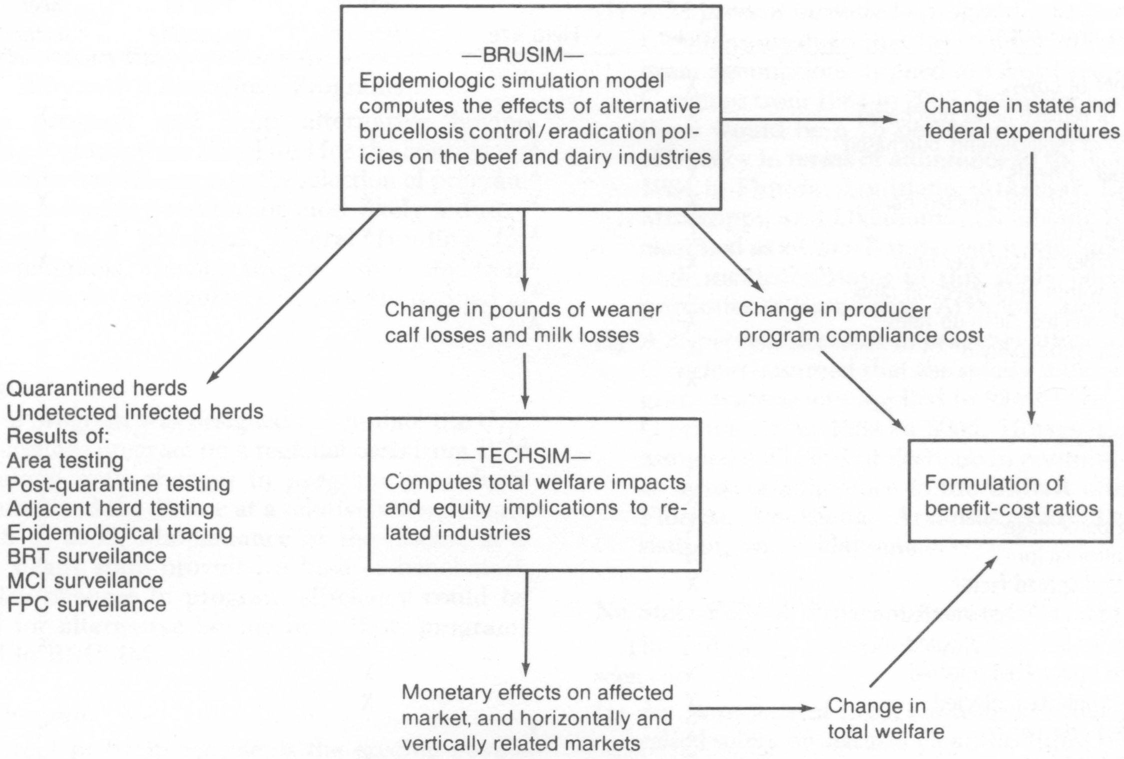


Figure 3. Regional demarcations of BRUSIM, United States, 1984.

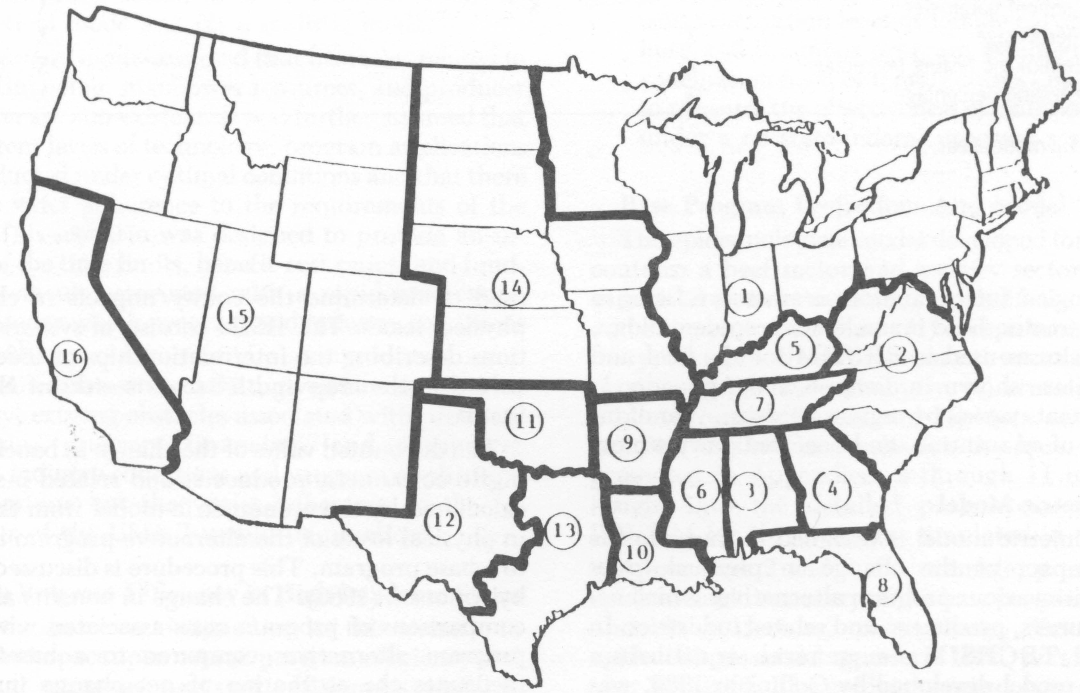


Table 3. BRUSIM input factors as related to region, herdsize, year of infection and quarantine, and beef and dairy sector, 1984

	Dimension of matrix					
Input matrix description	Region	Herd size	Year of infection	Year of quarantine	Beef sector	Dairy sector
Total number of cows	X				X	X
Proportion of replacements purchased	X				X	X
Source ratio of replacements purchased		X			X	X
Total number of herds	X	X			X	X
Number of undetected affected herds	X	X	X		X	X
Quarantined herds	X	X	X	X	X	X
Average number of cows per herd	X	X			X	X
Undetected within herd infection rates	X	X	X		X	X
Undetected infected clean-up rates	X	X	X		X	X
Regional sales probability	X				X	X
BRT Rate	X					X
Cull Rate*					X	X
Replacement rate*					X	X
MCI rate	X				X	X
FPC rate	X				X	X
FPC testing percentage	X				X	X
Quality control factor	X				X	X
Neighborhood spread factor	X	X			X	X
Weight loss for undected infected			X		X	X
Weight loss for detected infected			X		X	X
Milk loss for undetected infected	X		X			X
Milk loss for detected infected	X		X			X
Producer test cost per cow	X	X			X	X
Quarantine herd tests	X	X	X	X	X	X
Clean-up rate for quarantine herd tests	X	X	X	X	X	X
Residual infection rates	X	X			X	X
Weighted population proportions	X	X			X	X
Weighted infection rates	X		X		X	X
Area testing coefficients*	X				X	X
Contact herd year keys*	X				X	X
Number of contact herds	X				X	X
Percent contact herds tested	X				X	X
Herdsize management parameter		X			X	
Owner testing percentage	X				X	X
Secondary epidemiologic testing percentage	X				X	X
Post-quarantine testing percentage	X	X			X	X

*Dimensioned by model year.

Epidemiological factors and/or parameters relating to herd characteristics, herd management, epidemiology, and physical losses used in BRUSIM for the beef and dairy sectors are shown in Table 3 and Appendix 1. These coefficients varied by region, herdsize, year of infection, year of quarantine, and beef and dairy sector.

The Econometric Model

The econometric model is designed to measure the economic impact of the change in physical losses associated with various program alternatives which accrue to consumers, producers, and related industries. In this study, TECHSIM, a general equilibrium econometric model developed by Collins in 1980, was used to determine the equity impacts of changes in physical losses. TECHSIM consists of systems of equations describing the interrelationships of industries involved in the crop and livestock sectors of the United States.

The discounted value of the change in benefits accruing to consumers, producers, and related industries is calculated by the econometric model from the change in physical losses of the alternative program compared to a base program. This procedure is discussed in detail by Amosson (1983). The change in benefits along with comparisons of program costs associated with various program alternatives compared to a base program facilitates the estimation of net change in benefits, change in program costs and benefit-cost ratios for determining economic acceptability of the programs analyzed.

Scenarios Employed for Analyzing Alternative Brucellosis Programs

A base program and eight alternative bovine brucellosis programs were simulated for the contiguous 48 states. Prime consideration in the selection of program alternatives included potential or most likely industry requirements and potential federal funding for brucellosis programs. The nine programs simulated from 1976 to 2005 in the contiguous 48 states are defined as follows:

Base Program

The base program was designed to simulate the U.S. bovine brucellosis program on a regional basis from 1976 to 1984 along with changes in program procedures which maintained the disease at a relatively steady state from 1985 to 2005. Maintenance of the disease at a relatively steady state provided a base or benchmark from which changes in program efficiency could be measured for alternative bovine brucellosis programs simulated in BRUSIM.

Current Program

The current program represents the existing bovine brucellosis program in the contiguous 48 states from 1976 through 1984. Changes in program efficiencies and program progress which were incorporated in the U.S. bovine brucellosis program from 1976 to 1984 were then simulated from 1985 through 2005 to determine the effectiveness of the current bovine brucellosis program.

Eradication Programs

The eradication scenarios were modeled under a (1) theoretical mode and (2) a realistic mode.

(1) *Theorectical mode*-assumed that obstacles related to program financing, manpower resources, and producer cooperation are non-existent. It was further assumed that given current levels of technology, program applications were conducted under optimal conditions and that there would be strict adherence to the requirements of the UM&R. This scenario was designed to provide an indication of the time limits, benefit-cost ratios, and funding requirements associated with a rapid eradication program under which program and industry conditions are optimal.

(2) *Realistic mode*-assumed that, given current levels of technology, existing obstacles associated with producer cooperation, program financing, and manpower resources, industry conditions and program application would continue but that strict adherence to the requirements of the UM&R would be practiced.

Changes in Program Efficiency in High Incidence States

Two programs were designed under this scenario to measure the impact upon overall program efficiency and benefit-cost ratios as program efficiencies undergo change in high incidence or Class C states or regions while program efficiencies remained at 1984 base program levels in all other regions as follows.

(1) *A 25 percent increase in program efficiency in Class C regions*-assumed that the steady state or base program assumptions applied to Class Free, A, B, and C regions from 1984 to 2005. It further assumed that there would be a 25 percent increase in program efficiency in terms of adherence to the UM&R after 1984 in Florida, Louisiana, Arkansas, East Texas, Mississippi, and Oklahoma. Oklahoma is officially classified as a Class B state, but it was included with high incidence states in this study because of its proximity to East Texas, Arkansas, and Louisiana.

(2) *A 25 percent decrease in program efficiency in Class C regions*-assumed that the steady state or base program assumptions applied to Class Free, A, B, and C regions from 1984 to 2005. However, it further assumed a 25 percent decrease in program efficiency in terms of adherence to the UM&R after 1984 in Florida, Louisiana, Arkansas, East Texas, Mississippi, and Oklahoma.

No State-Federal Program Scenario

The following programs were modeled under this scenario.

(1) *No state-federal program*-assumed that producers relied solely on natural clean-up rates, no vaccination, and that there would be a milk ordinance enforced brucellosis program at producers' expense.

(2) *No state-federal program with calfhood vaccination supported by industry*-assumed that annual state-federal funding would be limited to $6 million, that producers rely solely on natural clean-up rates, and that there would be a milk ordinance enforced brucellosis program in dairy cattle. One of the programs modeled under this scenario assumed a 45 percent vaccination level of female calves entering the herd and the other program assumed a 75 percent vaccination level of female calves entering the herd to measure the effectiveness of calfhood vaccination under a no state-federal program scenario.

Base Program Projections And Model Validation

The epidemiological model developed for this research contains a beef sector and a dairy sector. Results are simulated on a national and regional basis for each beef and dairy sector as follows (1) an epidemiological summary, (2) a brucellosis program test summary, (3) a nonprimary surveillance summary, (4) brucellosis livestock producer expenditures, and (5) state and federal expenditures. Output results for the base program are presented in Appendices 2 through 11 to provide an insight into the detailed parameters generated by BRUSIM for the programs simulated in this study.

Appendices 2 and 3, for example, present the U.S. epidemiologic summary of the base program for the beef and dairy sectors, respectively. Year 1 in the epidemiologic model represents 1976, year 9 is 1984, and year 30 is 2005. The epidemiologic output generated by

BRUSIM for years 1 through 9 (1976-84) is identical for the base program and alternative programs since those years represent the bovine brucellosis programs existing in the contiguous 48 states during 1976-84. The epidemiologic summary provides projections of infected herds and infected cows, both quarantined and undetected, weaner calf and milk losses, and program expenditures. The simulation model, for example, projected total quarantined beef and dairy herds at 8,467 for 1984 (model year 9), Appendices 2 and 3. APHIS, U.S. Department of Agriculture records reported 8,449 quarantined beef and dairy herds for the contiguous 48 states during 1984, a deviation of 0.2 percent between projected versus actual quarantined herds.

The base program was designed to hold infection levels "relatively steady" from 1984 to 2005. This was accomplished with considerable success considering the fact that the epidemiologic model, BRUSIM, was designed to reflect the dynamics of the existing U.S. cattle industry by incorporating existing and projected changes in such factors as herd size, cattle numbers, and cattle cycles. This is demonstrated by the projections of infected herds, infected cows, weaner calf and milk losses, and total program costs in Appendices 2 and 3.

Data and information from APHIS Forms 4-33D and 4-35, as well as epidemiological data developed by APHIS personnel, were used to validate the epidemiological parameters and output generated by the epidemiological model. Projected quarantined herds, quarantined cows, on-farm tests, MCI cattle tested, and official vaccinates closely track official APHIS, U.S. Department of Agriculture, program data from 1976 through 1984, Appendices 12-16. For example, the average annual deviation for projected quarantined herds versus actual quarantined herds, without regard to sign, was 2.8 percent, Appendix 12. Average annual deviations for the projections in Appendices 12-16 versus APHIS program data were about 5 percent for 1976 through 1984.

Epidemiologic Analysis Of Alternative Programs

The current U.S. bovine brucellosis program plus seven alternative programs were simulated in BRUSIM to determine their epidemiological and physical impact upon the beef and dairy sectors. Economic analyses and related implications of these results are presented in the next section.

Table 4 summarizes the epidemiological and physical impact upon the beef and dairy sectors of alternative bovine brucellosis programs. Four programs, the theoretical eradication program, the realistic eradication program, the base program with a 25 percent increase in efficiency in Class C regions, and the current program, were highly efficient in reducing brucellosis infection and physical losses from 1984 to 2005. Brucellosis infection and physical losses increased substantially from 1984 to 2005 when the base program with a 25 percent reduction in Class C regions was implemented, but not as dramatically as under the three no program scenarios.

The theoretical eradication program, which assumed that finance, industry and manpower impediments were non-existent, with only current levels of technology or the "state of the arts" preventing immediate detection of all infected cattle, was most efficient with respect to reducing infection and physical losses. Although it is unrealistic to assume that all program conditions included under this program scenario exist in the real world environment, the results provide an estimate of the time required for achieving eradication when impediments to eradication are minimized.

Simulation results showed that almost 99 percent of the total infected cows could be eradicated within 3 years under the theoretical scenario. Depopulation of infected herds under this scenario varied with regional classification, herd-size, and year of infection. Herd depopulation schedules for the theoretical eradication program by regional classification and year of quarantine were as follows: (1) *first-year quarantine*-Free and Class A, 499 head or less; Class B, 99 head or less; Class C, 49 head or less; (2) *second-year quarantine*-Free and Class A, 999 head or less; Class B, 399 head or less; Class C, 199 head or less; (3) *third-year quarantine*-all herds in all classifications. Indemnity payments were based on $50 per head for commercial cattle and $250 per head for purebred cattle and dairy cows. Even then, very low levels of infection persisted for 10 to 12 years suggesting that total and immediate depopulation of all known infected herds may be essential for achieving rapid eradication when such levels of infection are present. Other problems may include the difficulty of detecting infection in small herds from which cattle are marketed infrequently and also problems associated with detecting vaccinated infected herds (Amosson and Dietrich 1984).

The realistic eradication scenario, which assumed progam budget levels similar to 1984 but a strict adherence to the requirements of the UM&R by all program personnel, demonstrated a potential to sharply reduce infection and physical losses, Table 4. Herd depopulation schedules for the realistic eradication program by regional classification were as follows: Free and Class A, 499 head or less; Class B, 399 head or less; and Class C, 199 head or less. Indemnity and depopulation payment schedules were identical to the theoretical eradication program. Using total infected cattle as a barometer, the realistic eradication program reduced total infected cattle 95 percent below the 1984 base level to about 7,200 head within 8 years (by 1992). The realistic eradication program would require about 14 years to decrease infection and physical losses to the same level accomplished by the theoretical scenario in 3 years. The theoretical program, however, enjoyed advantages over the realistic program stemming from the assumptions relative to the non-existence of program impediments other than state of the arts technology and higher depopulation schedules.

The base program with a 25 percent increase in efficiency in Class C regions was the third most efficient program followed closely by the current program with respect to reducing infection and physical losses, Table 4. By increasing the program efficiency 25 percent in Class C regions, the infection and physical loss

Table 4. Percentage change in quarantined herds, quarantined infected cows, undetected infected herds, undetected infected cows, total infected cows, weaner calf and milk losses, and total costs, by program alternative compared to the base program, United States, 1984 to 2005[a]

Item	Current program	Realistic eradication	Theoretical eradication	Baseline-25% increase in efficiency in C regions	Baseline-25% increase in efficiency in C regions	No program	No program with 45% calfhood vaccination	No program with 75% calfhood vaccination
	Percent Change							
Quarantined herds	-89.2	-99.2	-99.9	-94.9	-18.4	27,079.8[b]	4,909.4[b]	701.7[b]
Quarantined cows	-83.5	-99.8	-100.0[c]	-92.5	22.3	32,314.8[b]	4,747.7[b]	504.3[b]
Undetected infected herds	-86.3	-99.4	-100.0	-93.9	80.0	4,887.9	2,264.4	775.7
Undetected infected cows	-82.0	-99.2	-100.0[c]	-92.7	163.7	15,505.4	5,021.0	1,209.3
Total infected cows	-82.9	-99.5	-100.0[c]	-92.6	78.0	6,926.2	2,049.2	432.3
Weaner calf losses	-83.1	-99.5	-100.0[c]	-92.6	83.2	6,101.4	1,891.6	390.6
Milk losses	-80.5	-97.8	-99.7	-90.5	1.6	36,194.1	5,272.4	558.8
Total costs	-19.2	-50.1	-39.5	-22.6	1.9	-76.4	-65.8	-47.6

[a]1984 baseline simulation results for the above parameters were as follows: quarantined herds, 8,467; quarantined cows, 88,756; undetected infected herds, 12,008; undetected infected cows, 57,724; total infected cows, 146,480; weaner calf losses, 19,454,818 (pounds); dairy milk losses, 98,680 (hundredweight); and total costs, $168,894,576. NOTE: Quarantined herds and cows for the no program scenarios reflect identified infected dairy herds and dairy cows only.

[b]Reflects changes in identified infected dairy herds and cows only after 1984. Quarantined dairy herds and cows in 1984 were 297 and 3,961, respectively.

[c]Less than 0.005 percent.

parameters were generally decreased 92 percent or more by 2005 compared to 1984. Comparable reductions in infections and losses for the current program were generally in the low- to mid-80 percent range.

The base program with a 25 percent reduction in efficiency in Class C regions resulted in substantial increases in infection and physical losses, Table 4. Because of program inefficiencies, quarantined herds declined as program efficiencies were decreased, but undetected infected herds and cows, total infected cows, and weaner calf losses increased 80 percent or more by 2005 over 1984.

Changes in program efficiency in Class C regions had the greatest impact on program parameters within Class C regions, although they also had a strong indirect impact on non-Class C regions (Class Free, A and B regions). Total infected cows, for example, decreased more than 80 percent in Class C regions and almost 40 percent in non-Class C regions during 1990 when program efficiency was increased 25 percent in Class C regions. Further, total infected cows decreased 98 percent in Class C regions by 2005, compared to a 70 percent decline in non-Class C regions as a result of the increased efficiency in Class C regions. Similarly, a 25 percent decrease in program efficiency in Class C regions resulted in a 12 percent increase in total infected cows by 1990 in Class C regions compared to a 2 percent increase in non-Class C regions. By 2005, total infected cows had increased more than 80 percent in Class C regions, compared to a 32 percent increase in non-Class C regions, when program efficiency was decreased 25 percent in Class C regions. These results demonstrate the direct impact of changes in program efficiency upon the regions where such changes are incorporated, and the "spill-over" effect from changes in program efficiency in Class C regions to non-Class C regions.

The three no program scenarios, including the no program and the no program with a 45 percent and a 75 percent calfhood vaccination level, all revealed sharp increases in infection and physical loss parameters compared to the current program and the other program alternatives analyzed, Table 4. Total infected cows, for example, increased more than 69-fold under the no program scenario, more than 20-fold under the no program plus 45 percent calfhood vaccination scenario, and more than 4-fold under the no program plus 75 percent calfhood vaccination scenario by 2005 compared to 1984. It is significant to note that calfhood vaccination reduced infection and physical losses as calfhood vaccination levels increased under the no program scenario. It is also significant to note, however, that even at calfhood vaccination levels of 75 percent under the no program scenario, both infection and physical losses were a minimum of 3-fold to a maximum of 13-fold higher than the other non-program alternatives, Table 4.

The importance of program efficiency levels, strict adherence to the UM&R by individuals and agencies, and decisions regarding program components as adjacent herd testing and depopulation are highlighted by the simulation results with respect to quarantined and infected beef and dairy herds in Tables 5 and 6. This is especially important with respect to the simulation results for the theoretical and realistic eradication programs, the base program with a 25 percent increase in program efficiency in Class C regions, and the current program. Decisions concerning depopulation schemes, for example, are paramount depending upon the time frame desired for achieving eradication. Table 6 revealed that low levels of infection existed in the theoretical eradication program from 1990 to 2005 even under assumptions of high program efficiency levels since depopulation for larger infected herds occurred only after infected herds were in their third year of quarantine. These results suggest that low levels of infection would likely remain in the cattle population, even at high program efficiency levels, in the absence of total eradication of known infected herds at a specific minimum level of infection.

Table 7 further illustrates the importance of decisions concerning depopulation along with high levels of program efficiency to assure identification of relatively high proportions of infected herds. For example, implementation of the theoretical eradication program in 1985 resulted in a 95 percent decrease of undetected infected herds from 1984 to 1985. These results, which were influenced by high efficiency levels in such program components as secondary epidemiologic tracing, adjacent herd testing, and post-quarantine testing along with a depopulation program, resulted in a decrease in total infected herds of 88 percent from 1984 to 1986 and almost 96 percent from 1984 to 1987 in the theoretical program. The rapid decrease in infection in the theoretical program is primarily because of the relatively higher program efficiency levels assumed than currently exist, especially in the Class C regions. Implementation of the realistic eradication program, although highly effective, resulted in a decrease of undetected herds of almost 30 percent from 1984 to 1985, Table 7. Total infected herds in the realistic eradication program, which also assumed a lower depopulation scheme than did the theoretical eradication program, decreased 40 percent from 1984 to 1986 and 55 percent from 1984 to 1987.

Simulation results for such program parameters as quarantined, undetected, and total infected beef and dairy cows, including weaner calf and milk losses (Appendices 17-21), parallel the simulation results for quarantined and undetected infected beef and dairy herds. Decreases in infection and physical losses were achieved most rapidly by the theoretical eradication program by 1990, as anticipated, followed by the realistic eradication program, the base program with a 25 percent increase in efficiency in Class C regions, and the current program. The realistic eradication program and the base program with a 25 percent increase in efficiency in Class C regions, other than the theoretical eradication program, continued to make the most progress leading toward eradication from 1990 to 2005. The base program with a 25 percent decrease in efficiency in Class C regions revealed substantial increases in infection, but not as dramatically as the three no program scenarios. For example, total infected cows for the three no program scenarios, depending upon vaccination levels, were from 30 to more than 400 times greater than those for the current program by 2005.

Economic Analysis of Alternative Programs

Economic considerations for determining the acceptability of alternative programs in this study include such criteria as benefit-cost ratios, changes in benefits, net change in benefits, and change in program costs. In addition to these criteria, it is important to analyze the equity implications of changes in physical losses and benefits not only to producers, but to consumers and related industries. Benefits or losses to society are an important consideration in analyzing the economic impact of alternative bovine brucellosis programs since the major source of funding for such programs is from public funds.

A primary criterion used for analyzing the acceptability of alternative programs was benefit-cost ratios. Benefit-cost ratios are calculated by dividing the present value of the projected change in benefits over the relevant planning horizon by the present value of the projected change in costs. Benefit-cost ratios, which are greater than one, are generally construed as economically acceptable. Since many programs or projects derive benefits and costs beyond the inception of the program, it is necessary to sum the benefits and costs over the entire time horizon of the program analyzed. The change in benefits and program costs accruing to alternative programs compared to the base program resulting from changes in infection were calculated in 1982 real dollars using a 4 percent discount rate.[2] This procedure places benefits and costs on a common time pattern while application of the discount rate results in conversion of benefits and costs to a present value basis for the entire time horizon analyzed.

Other criteria used for determining economic acceptability or program ranking include net change in benefits (net present value) and change in program costs. The net change in benefits is defined as the present value of the change in benefits minus the change in program costs.

In estimating changes in economic benefits which accrue to each alternative program, the differences in the market value of annual beef and milk losses associated with each program alternative were measured from the levels of losses projected for the base program. The equity impact of such changes in physical losses upon con-

[2]The real discount rate in this report is the nominal interest rate for non-real estate loans, minus the rate of change in the consumer price index for all items as reported by the U.S. Department of Commerce.

Table 5. Quarantined beef and dairy herds, by program, United States, 1975-2005[a]

Year	Baseline program	Current program	Realistic eradication	Theoretical eradication	Baseline 25% increase in efficiency in C regions	Baseline 25% decrease in efficiency in C region	No program[b]	No program with 45% calfhood vaccination[b]	No program with 75% calfhood vaccination[b]
1976	14,407	14,407	14,407	14,407	14,407	14,407	14,407	14,407	14,407
	1,445	1,445	1,445	1,445	1,445	1,445	1,445	1,445	1,445
	15,852	15,852	15,852	15,852	15,852	15,852	15,852	15,852	15,852
1980	11,294	11,294	11,294	11,294	11,294	11,294	11,294	11,294	11,294
	843	843	843	843	843	843	843	843	843
	12,137	12,137	12,137	12,137	12,137	12,137	12,137	12,137	12,137
1985	5,072	6,976	8,710	13,069	8,431	4,963	0	0	0
	254	234	388	432	241	250	425	425	425
	5,326	7,210	9,098	13,501	8,672	5,213	425	425	425
1990	3,912	2,699	1,305	45	1,565	4,078	0	0	0
	214	118	99	14	85	222	2,586	1,437	852
	4,126	2,817	1,404	59	1,650	4,300	2,586	1,437	852
1995	3,976	1,720	372	6	800	4,464	0	0	0
	214	75	35	6	49	243	11,653	3,432	1,089
	4,190	1,795	407	12	849	4,707	11,653	3,432	1,089
2000	4,046	1,192	113	1	488	5,139	0	0	0
	218	53	17	5	35	280	35,532	7,519	1,597
	4,264	1,245	130	6	523	5,419	35,532	7,519	1,597
2005	4,483	880	55	1	406	6,590	0	0	0
	213	37	11	5	29	320	80,724	14,878	2,381
	4,696	917	66	6	435	6,910	80,724	14,878	2,381

[a]Data by year and program reflect beef, dairy and total, respectively.
[b]Quarantined dairy herds after 1984 are identified infected dairy herds.

Table 6. Undetected infected beef and dairy herds, by program, United States, 1976-2005[a]

Year	Baseline program	Current program	Realistic eradication	Theoretical eradication	Baseline— 25% increse In efficiency in C regions	Baseline— 25% decrease in efficiency in C regions	No program	No program with 45% calfhood vaccination	No program with 75% calfhood vaccination
1976	21,784	21,784	21,784	21,784	21,784	21,784	21,784	21,784	21,784
	218	218	218	218	218	218	218	218	218
	22,002	22,002	22,002	22,002	22,002	22,002	22,002	22,002	22,002
1980	19,359	19,359	19,359	19,359	19,359	19,359	19,359	19,359	19,359
	114	114	114	114	114	114	114	114	114
	19,473	19,473	19,473	19,473	19,473	19,473	19,473	19,473	19,473
1985	12,479	10,445	8,518	654	8,891	12,585	21,916	21,916	21,916
	38	31	24	3	30	38	174	174	174
	12,517	10,476	8,542	657	8,921	12,623	22,090	22,090	22,090
1990	11,130	5,344	1,827	28	2,686	12,327	63,853	48,757	39,420
	28	14	5	0	12	28	708	365	200
	11,158	5,358	1,832	28	2,698	12,355	64,561	49,122	39,620
1995	11,376	3,689	562	4	1,530	14,399	190,023	98,888	54,659
	27	9	2	0	7	29	3,266	919	280
	11,403	3,698	564	4	1,537	14,428	193,289	99,807	54,939
2000	10,869	2,226	158	1	905	16,452	383,697	180,262	76,611
	26	7	1	0	5	30	10,139	2,125	438
	10,895	2,233	159	1	910	16,482	393,836	182,387	77,049
2005	11,887	1,644	69	0	730	21,585	577,057	279,913	104,515
	26	5	1	0	5	34	21,892	4,010	645
	11,913	1,649	70	0	735	21,619	598,949	283,923	105,160

[a]Data by year and program reflect beef, dairy, and total, respectively.

Table 7: Quarantined and undetected beef and dairy herds, theoretical and realistic eradication programs, by year, United States, 1984-90

Program and year	Beef herds		Dairy herds		Total herds		
	Quarantined	Undetected infected	Quarantined	Undetected infected	Quarantined	Undetected infected	Total infected
Theoretical eradication:							
1984	8,170	11,970	297	38	8,467	12,008	20,475
1985	13,069	654	432	3	13,501	657	14,158
1986	1,814	442	298	2	2,112	444	2,556
1987	561	180	146	0	707	180	887
1988	223	80	41	0	264	80	334
1989	91	44	24	0	115	44	159
1990	45	28	14	0	59	28	87
Realistic eradication:							
1984	8,170	11,970	297	38	8,467	12,008	20,475
1985	8,710	8,518	388	24	9,098	8,542	17,640
1986	5,464	6,511	300	19	5,764	6,530	12,294
1987	3,979	4,852	234	14	4,213	4,866	9,079
1988	2,910	3,591	188	9	3,098	3,600	6,698
1989	2,163	2,399	133	7	2,296	2,406	4,702
1990	1,305	1,827	99	5	1,404	1,832	3,236

sumers, producers, and related industries is dependent upon such factors as direction of change in infection, elasticity of demand for beef and milk, infection status of producers, etc. The ramification of these considerations is discussed in detail by Amosson (1983) and Liu (1979).

Before analyzing the equity impact of changes in benefits, benefit-cost ratios, and other selected economic criteria, it is important to analyze the annual state-federal, producer, and total costs associated with the various programs simulated, Table 8. The state-federal expenditures simulated by BRUSIM closely track actual state-federal expenditures as reported by APHIS, U.S. Department of Agriculture after adjusting for the reported state (non-federal) expenditures which included producer expenditures but which were reported as state or non-federal expenditures. This adjustment was necessary to assure that costs were not duplicated since BRUSIM calculates total producer expenditures separately from state-federal expenditures.

With the exception of the three no program scenarios, annual program costs for the alternative programs by 2005 were lowest for the realistic eradication program, followed by the theoretical eradication program, the base program with a 25 percent increase in efficiency in Class C regions, and the current program (Table 8). Although infection under the theoretical eradication program was virtually eliminated by 1990, program costs for this program remained at relatively high levels because program activities associated with SPT and FPC remained at high levels of activity and efficiency throughout the time horizon simulated. While secondary epidemiologic tracing and adjacent herd testing efficiency levels also remained at high levels, the activities associated with these program components tended to decrease as infection levels or primary source herds decreased.

Producer costs which accumulate under the no program scenario reflect producer costs associated with an assumed city/municipal milk ordinance enforced BRT system. The additional producer costs which accumulate under the no program scenario with 45 percent and 75 percent calfhood vaccination reflect producer costs associated with maintaining calfhood vaccination at the specified levels from 1985 to 2005.

Total annual costs associated with the theoretical eradication program, the realistic eradication program, the base program with 25 percent increase in efficiency in Class C regions, and the current program were lower than annual costs in the base program for all years except the first 3 or 4 years of the simulation period after 1984, Table 8. Lower annual program costs along with declining infection levels of the above programs compared to the base program indicate they were both more cost efficient and more epidemiologically efficient than the base program. For example, annual program costs for the realistic eradication program were above annual costs of the base program from 1985 through 1987, but below annual costs of the base program at a decreasing rate from 1988 to 2005, Figure 4. Higher annual program costs for the realistic eradication program from 1985 through 1987 compared to the base program results from higher program efficiency levels associated primarily with the MCI program and secondary epidemiological

Table 8. State-federal, producer, and total bovine brucellosis costs, by program, United States, 1976-2005[1]

Year	Baseline program	Current program	Realistic eradication	Theoretical eradication	Baseline—25% increase in efficiency in C regions	Baseline—25% decrease in efficiency in C regions	No program	No program with 45% calfhood vaccination	No program with 75% calfhood vaccination
	Thousand dollars								
1976	122,835	122,835	122,835	122,835	122,835	122,835	122,835	122,835	122,835
	50,082	50,082	50,082	50,082	50,082	50,082	50,082	50,082	50,082
	172,917	172,917	172,917	172,917	172,917	172,917	172,917	172,917	172,917
1980	103,185	103,185	103,185	103,185	103,185	103,185	103,185	103,185	103,185
	48,463	48,463	48,463	48,463	48,463	48,463	48,463	48,463	48,463
	151,648	151,648	151,648	151,648	151,648	151,648	151,648	151,648	151,648
1985	85,474	95,818	112,366	131,816	101,540	84,921	0	0	0
	50,930	55,249	51,613	51,388	55,018	50,772	556	36,278	65,709
	136,404	151,067	163,979	183,204	156,558	135,693	556	36,278	65,709
1990	78,481	76,336	69,959	54,753	74,221	80,004	0	0	0
	49,525	50,626	34,023	39,746	48,045	49,817	2,351	37,740	67,190
	128,006	126,962	103,982	94,499	122,266	129,821	2,351	37,740	67,190
1995	83,334	74,901	57,165	54,015	71,502	85,919	0	0	0
	52,200	51,742	31,270	38,981	49,198	53,000	7,671	43,334	74,478
	135,534	126,643	88,435	92,996	120,700	138,916	7,671	43,334	74,478
2000	89,534	76,893	51,158	59,249	72,911	94,764	0	0	0
	56,093	54,857	32,176	43,035	52,258	57,756	20,271	48,005	78,611
	145,627	131,750	83,334	102,284	125,169	152,520	20,271	48,005	78,611
2005	97,214	78,634	51,453	59,317	75,420	107,948	0	0	0
	60,674	57,830	32,815	42,790	55,325	64,089	39,788	57,717	88,458
	157,888	136,464	84,268	102,107	130,745	172,037	39,788	57,717	88,458

[a]Costs by year and program reflect state-federal, producer, and total costs, respectively. Costs are in 1982 dollars.

program components of adjacent herd testing, post quarantine testing, and epidemiologic tracing. The net results were that infection decreased as well as associated program costs.

Questions often arise concerning equity impacts of expenditures for publicly funded programs such as brucellosis. Table 9 reveals the benefits accruing to consumers, producers, and related agricultural industries from changes in weaner calf losses associated with alternative programs compared to the base program. Beef and dairy weaner calf losses were decreased most dramatically by the theoretical eradication program followed by the realistic eradication program, the base program with a 25 percent increase in efficiency in Class C regions, and the current program, Appendix 20. Beef and dairy weaner calf losses increased for all other alternative programs simulated compared to the base program. Consumers are the largest beneficiaries from efficient bovine brucellosis programs which decrease weaner calf losses as the theoretical and realistic eradication programs, the base program with a 25 percent increase in efficiency, and the current program, Table 9. Consumers incur the largest decrease in benefits when weaner calf losses increase as under the no program scenarios. The net results are that programs which decrease weaner calf losses increase supplies of beef and exert a downward pressure on price which is favorable to consumers. Benefits to related agricultural industries, which provide services and/or products to the cattle industry, parallel benefits to consumers but at a lower level, Table 9.

Producers are faced with a dilemma with respect to economic implications arising from the alternative programs simulated. Producers with affected herds can and often do incur catastrophic economic losses from infection in their herds. Producers whose herds remain free of infection through good herd health management practices tend to benefit at the expense of infected herd owners since they tend to receive higher prices for beef when supplies are decreased as a result of infection. The net results are that programs which decrease weaner calf losses will increase beef supplies and depress prices at the producer level as shown in Table 9. The opposite results can be anticipated for cattle producers as weaner calf losses increase and beef supplies decrease.

The overall results are that positive benefits accrue to society from programs which decrease weaner calf losses, Table 9. Care should be exercised in placing undue emphasis on the absolute values generated in Table 9 since the direction of anticipated change in benefits accruing to alternative programs is of prime consideration. For example, the results show that the largest decrease in total benefits accrues from the no program scenarios and the greatest positive benefits to society are projected to result from the eradication programs.

Program benefits and program costs associated with

Figure 4. Comparison of base program and realistic eradication total program costs, 1985-2005.

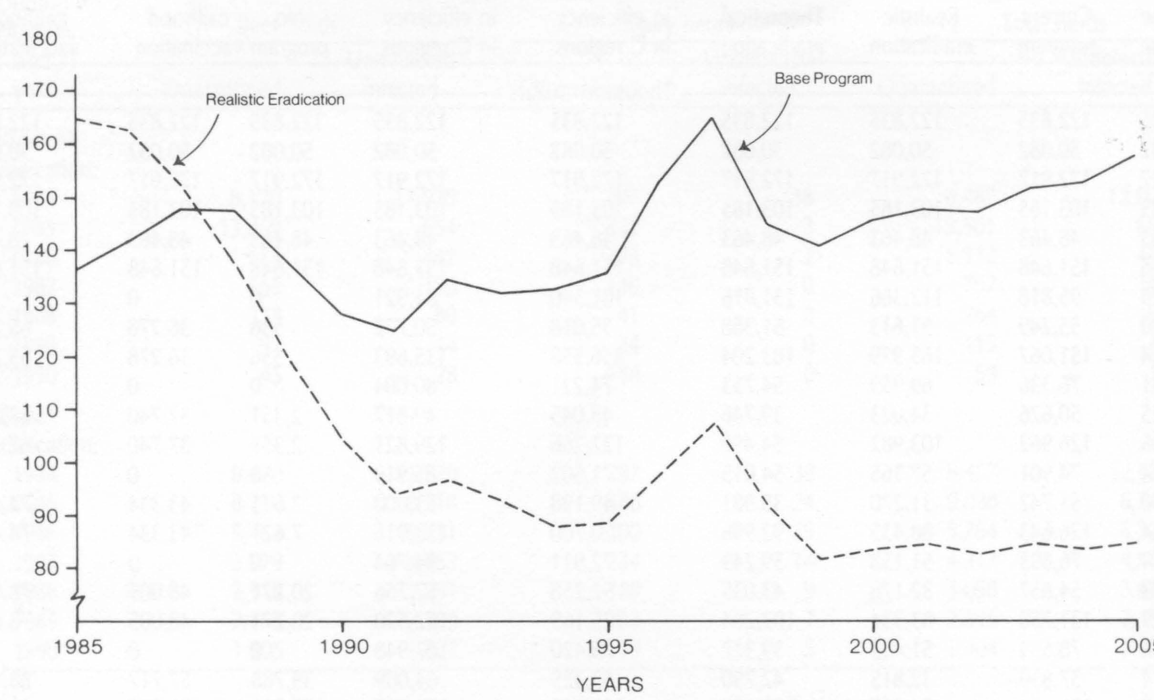


Table 9. Change in benefits from weaner calf losses which accrue to consumers, livestock producers, related agricultural industries, and total benefits, by program alternative compared to the base program, United States

Program alternative	Change in consumer benefits	Change in livestock producer benefits	Change in related agricultural industry benefits	Change in total benefits
	Million dollars			
Current	552.64	-225.18	140.13	467.59
Realistic eradication	848.63	-345.50	220.23	723.36
Theoretical eradication	961.01	-391.06	256.11	826.06
Baseline-25% increase in efficiency in Class C regions	724.31	-295.00	198.47	627.78
Baseline-25% decrease in efficiency in Class C regions	-280.07	114.40	-39.63	-205.30
No program	-23,905.03	9,564.62	-2,620.34	-16,960.75
No program with 45% calfhood vaccination	-7,271.71	2,952.50	-866.82	-5,186.03
No program with 75% calfhood vaccination	-1,810.54	737.68	-269.93	-1,342.79

Table 10. Summary of program alternatives, by selected criteria, compared to the base program[a]

Program alternative	Change in producer and consumer benefits	Total program costs	Total annual increase in program costs	Total annual decrease in program costs	Net change in program costs	Net change in producer and consumer benefits
	Million dollars					
Current	473.50	2,089.33	27.33	94.98	-67.65	540.96
Realistic eradication	733.12	1,732.60	45.16	469.54	-424.38	1,157.50
Theoretical eradication	837.70	1,728.69	41.60	469.89	-428.29	1,265.99
Baseline-25% increase in efficiency in class C regions	636.05	2,032.54	30.52	154.96	-124.44	760.49
Baseline-25% decrease in efficiency in class C regions	-206.15	2,203.55	47.88	1.31	46.57	-252.72
No program	-18,338.17	447.14	0	1,709.84	-1,709.84	-16,628.33
No program with 45% calfhood vaccination	-5,429.78	872.69	0	1,284.29	-1,284.29	-4,145.49
No program with 75% calfhood vaccination	-1,387.93	1,267.32	0	889.66	-889.66	-498.27

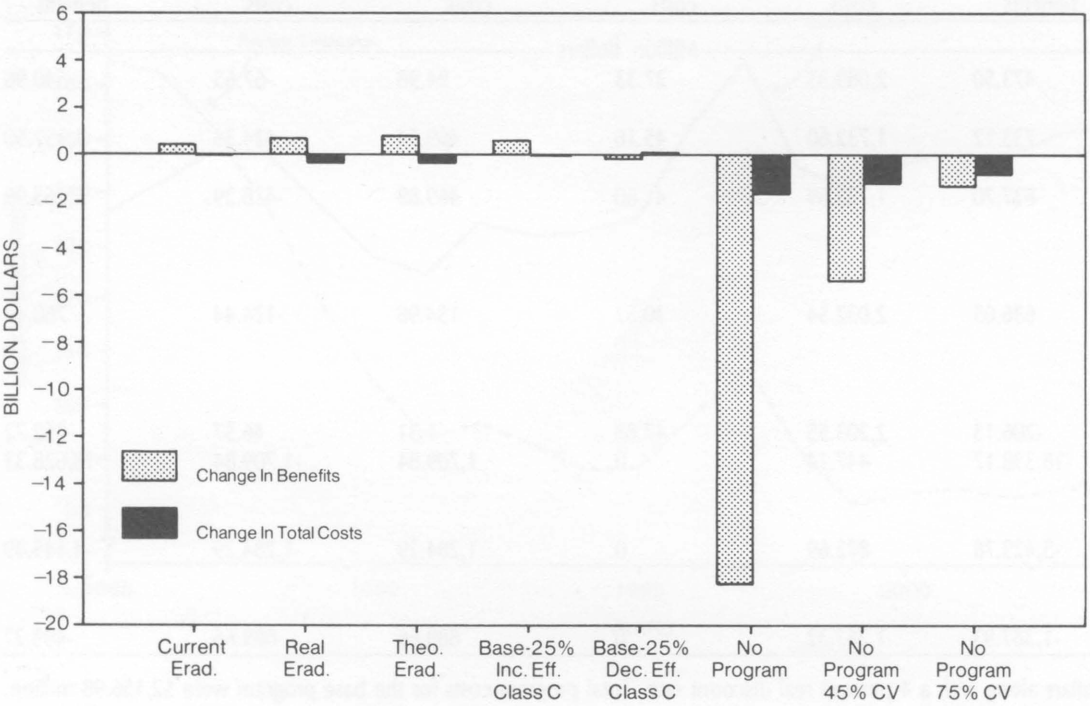
[a]Dollars are in 1982 real dollars along with a 4 percent real discount rate. Total program costs for the base program were $2,156.98 million.

alternative programs are presented in Table 10 and Figure 5. The largest positive change in benefits to society resulted from the theoretical eradication scenario, followed by the realistic eradication scenario, the baseline with 25 percent increased efficiency in Class C regions, and the current program. The largest negative change in benefits or loss to society resulted from the no program scenario with accumulated losses to 2005 exceeding $18 billion. Programs with the next largest losses were the other two no program scenarios with 45 percent and 75 percent calfhood vaccination, respectively. The baseline program with a 25 percent reduction in efficiency in Class C regions also exhibited a loss in benefits to society exceeding $206 million.

The relative large positive change in benefits accruing to society from the eradication programs reflects the decreases in physical losses of meat and milk in these programs compared to the base program. Such decreases in physical losses result from increased efficiency in detection of infected herds, depopulation of detected infected herds as specified, and the decline in the spread of infection as infected cattle are eliminated. While the annual cost of some programs, as the realistic eradication program, exceeded the annual base program costs for the first 3 years (Figure 4), program costs for the remainder of the time horizon simulated were below the base program costs resulting in net declines of more than $424 million in total costs of the realistic eradication program compared to the base program, Table 10. Similarly, the base program with a 25 percent increase in program efficiency in Class C regions demonstrated that increased program effort in high incidence states, even though annual program costs increased over the base program during the first 4 years, resulted in substantial reduction of infection during the life of the program. In addition, program costs declined almost $125 million compared to the base program. The current program paralleled the base program with a 25 percent increase in efficiency in Class C regions but at a slightly lower level with respect to reductions in physical losses and total program costs.

Although the largest declines in program cost accrued to the no program scenarios, accompanying declines in benefits to society because of large increases in infected herds and cattle were even more dramatic. Analysis of the total annual decrease in program costs versus change in benefits to producers and consumers (society) revealed that for each $1 decline in program costs of the no program scenario, benefits to society declined more than $10 compared to the base program, Table 10. Similar comparisons of the no program scenarios with 45 percent and 75 percent calfhood vaccination resulted in declines of $4.23 and $1.56 in total benefits, respectively, for each $1 decline or savings in program cost of these no program scenarios. While relatively large negative declines in total benefits result from the no program

Figure 5. Change in total producer and consumer benefits and change in program cost, by alternative bovine brucellosis program, compared to the base program, United States, 1985-2005.



scenario, declines in benefits are mitigated as the level of vaccination is increased. All other programs, with the exception of the base program with a 25 percent decrease in efficiency in Class C regions, revealed positive net changes in total benefits over the time horizon simulated.

Benefit-cost ratios revealed similar patterns of acceptability and ranking as did net change in total benefits, Table 11. Benefit-cost ratios which exceed 1.0 are economically acceptable. When the base program is used as the base (Column 1, Table 11) for estimating benefit-cost ratios, the eradication programs, the baseline program with a 25 percent increase in efficiency in Class C regions, and the current program are economically acceptable. However, the no program scenarios and the base program with a 25 percent reduction in efficiency in Class C regions all had benefit-cost ratios under 1.0 indicating economic unacceptability. This was especially true for the no program and the no program with a 45 percent calfhood vaccination level. When the no program with 45 percent and 75 percent calfhood vaccination levels are used as a base (Columns 7, 8, and 9, Table 11) it is evident that the eradication programs, the baseline program with a 25 percent increase in efficiency in Class C regions, and the current program are economically desirable programs compared to the three no program scenarios. When the no program is used as a base, the relative high benefit-cost ratios of the no program scenarios with a 45 percent and 75 percent calfhood vaccination level demonstrate the benefits accruing to vaccination programs if state-federal brucellosis programs were eliminated. These benefit-cost ratios suggest that additional expenditures for vaccination under no program scenarios would be highly beneficial.

A summary of the rankings of program alternatives by selected economic criteria is shown in Table 12. The two eradication scenarios, including the theoretical and the realistic programs, reduced infection and meat and milk losses to lower levels and at a faster rate than other programs analyzed. The efficiency of these two programs is revealed in Table 12 where theoretical and realistic eradication programs ranked 1 and 2, respectively, in total and net change in consumer benefits, and benefit-cost ratios. The base program with a 25 percent increase in efficiency in Class C regions and the current program ranked third and forth, respectively, in total and net change in benefits and benefit-cost ratios. The no program scenarios ranked below all other program alternatives simulated, except in program cost, where they ranked above other programs because of greater reductions in program costs. However, this larger reduction in program costs compared to other programs simulated was offset by proportionally larger decreases in benefits to society resulting in negative benefit-cost ratios to society from the no program scenarios.

Table 11. Comparison of regular benefit-cost ratios, by alternative bovine brucellosis programs, United States, 1985-2005[a]

Program versus base	Base								
	Baseline program	Current program	Realistic eradication	Theoretical eradication	Baseline—25% increase in efficiency in C regions	Baseline—25% decrease in efficiency in C regions	No program	No program with 45% calfhood vaccination	No program with6h 75% calfhood vaccination
	Ratio								
Current program	1.26	—	0.71	0.65	0.90	1.38	9.22	3.24	1.50
Realistic eradication	1.68	1.36	—	0.94	1.23	1.81	11.27	4.06	1.96
Theoretical eradication	1.73	1.42	1.06	—	1.29	1.88	11.35	4.13	2.02
Baseline-25% increase in efficiency in C region	1.37	1.11	0.80	0.75	—	1.50	9.56	3.41	1.62
Baseline-25% decrease in efficiency in C region	0.89	0.64	0.36	0.31	0.54	—	8.43	2.77	1.11
No program	-36.19	-37.40	-38.78	-39.02	-37.89	-35.62	—	-26.92	-35.07
No program with 45% calfhood vaccination	-3.75	-4.37	-5.08	-5.20	-4.62	-3.46	15.30	—	-3.18
No program with 75% calfhood vaccination	0.61	0.18	-0.31	-0.39	0.01	0.81	13.73	3.88	—

[a]Benefit-cost ratio of the current program versus the baseline program is calculated as change in benefit under the current program relative to the baseline program costs/current program costs. Change in benefits are the sum of producer and consumer benefits.

Summary and Implications

The Cooperative State-Federal Brucellosis Eradication Program, established in 1934, has been highly successful in reducing brucellosis infection in U.S. cattle herds. This is demonstrated by a decrease in reactor rates from 11.5 percent in 1935 (Becton 1977) to a MCI reactor rate of 0.3 percent in 1984 (Beal 1985). Weaner calf and milk losses to producers decreased from $100 million in the 1940's (Becton 1977) to $32 million in 1983 (Beal 1984). Forty states, classified Class Free or Class A in 1985, accounted for two-thirds of the U.S. cow population and 5 percent of the quarantined herds. The remaining 10 states, classified Class B or Class C, contained about one-third of the U.S. cow population and 95 percent of the U.S. quarantined cattle herds as of March 1985. The net results are that 31 states accounted for one or more quarantined herds during 1985 with more than three-fourths of the quarantined herds concentrated in the five states or regions currently classified Class C.

The purpose of this research was to analyze the economic and epidemiologic impact of specified alternative bovine brucellosis programs for Veterinary Services, APHIS, U.S. Department of Agriculture, and to provide a benefit-cost analysis of these alternative brucellosis control and eradication strategies. These strategies and/or alternative brucellosis programs were examined in terms of their costs and benefits to society, consumers, producers, and related agricultural industries. In addition, alternative criteria such as change in benefits, change in program costs, and net benefits were estimated to provide guidelines to decision makers concerning optimum alternative bovine brucellosis control and/or eradication programs.

BRUSIM, a systems simulation model, was developed to measure the impact of various program components

Table 12. Ranking of program alternatives, by selected criteria, compared to the base program

Program alternative	Change in producer and consumer benefits	Net change in producer and consumer benefits	Change in program costs	Regular benefit-cost ratio
Current program	4	4	7	4
Realistic eradication	2	2	5	2
Theoretical eradication	1	1	4	1
Baseline-25% increase in efficiency in C regions	3	3	6	3
Baseline-25% decrease in efficiency in C regions	5	5	8	5
No program	8	8	1	8
No program with 45% calfhood vaccination	7	7	2	7
No program with 75% calfhood vaccination	6	6	3	6

upon selected epidemiologic parameters and to determine associated costs and physical losses of brucellosis control/eradication programs, given epidemiologic coefficients and economic criteria from 1976 through 2005. The United States was divided into 16 regions based upon such factors as prevalence, producer characteristics, and cattle population.

TECHSIM, an econometrics model, was used for determining the net benefits accruing to society, consumers, producers, and related industries as a result of changes in beef and milk losses from alternative programs compared to a base program. The discounted values and associated program costs were used for determining benefit-cost ratios and related economic decision criteria.

A base program and eight alternative bovine brucellosis programs were simulated for the contiguous 48 states. Prime consideration in the selection of program alternatives included potential or most likely industry requirements and potential federal funding for brucellosis programs. The nine programs simulated for 1976 to 2005 included the following: (1) base program, (2) current (1976-84) program, (3) rapid eradication with theoretical and realistic modes, (4) base program with 25 percent increase in program efficiency in Class C regions, (5) base program with 25 percent decrease in program efficiency in Class C regions, (6) no state-federal program with no vaccination, and (7) no state-federal program with calfhood vaccination supported by industry.

Major findings resulting from the alternative bovine brucellosis programs analyzed in this study are as follows:

(1) *Control and/or eradication of brucellosis infection.* Four programs, the theoretical eradication program, the realistic eradication program, the base program with a 25 percent increase in efficiency in Class C regions, and the current program, were highly effective in reducing brucellosis infection from 1984 to 2005. The theoretical eradication program demonstrated that eradication could be achieved within 3 to 5 years when program constraints are eliminated with the only limiting factors being the current state of technology. These results demonstrate that the current state of technology is sufficient to achieve eradication. The time frame for achieving eradication will depend on financial and manpower commitment, level of program efficiency, producer and agency cooperation, and depopulation programs for known infected herds. These research results parallel the recent field experience of the Canadian Department of Agriculture (Agriculture Canada 1985) which reported no known bovine brucellosis infection in Canada since March 1984 after initiating a strong market cattle testing program, along with an indemnity and depopulation program which encouraged producer cooperation in 1979.

The realistic eradication program, which assumed 1982-84 funding levels, strict adherence to the UM&R by program authorities, and a modified depopulation scheme, reduced total infected cows by more than 92 percent from 1984 to 1990. Increased emphasis on depopulation of detected herds, although increasing program costs in the realistic eradication program, would likely have decreased infected cows at a faster rate than reported above. The net results are that the realistic eradication program would be a powerful tool leading to eradication given increased producer cooperation through incentives or educational programs plus producer incentives for depopulating known infected herds.

The base program with a 25 percent increase in program efficiency in Class C regions, although revealing infection levels ranging from 5 to 7 percent higher in all infection parameters than did the realistic eradication program by 2005, was more effective in reducing infection than the current program. Results reveal that a 25 percent increase in program efficiency in high incidence or Class C regions through stricter adherence to the UM&R or other incentives would be highly effective in reducing infection levels.

The base program with a 25 percent decrease in program efficiency in Class C regions demonstrated that reductions in program efficiency in high incidence regions would result in substantial increases in infection. The most dramatic increases in bovine brucellosis infection were generated by the three no state-federal program scenarios. Total infected cows increased 69-fold under the no state-federal program without calfhood vaccination from 1984 to 2005 compared to a 4-fold increase in infected cows for the no program scenario with a 75 percent calfhood vaccination level. These results demonstrate that (1) calfhood vaccination would be highly beneficial under a no state-federal program scenario or when bovine brucellosis infection exists at relatively high levels and (2) no state-federal programs with calfhood vaccination, even at high levels of calfhood vaccination, were substantially inferior with respect to reducing bovine brucellosis infection compared to other alternative programs simulated.

(2) *Reduction of phyical losses.* Weaner calf and milk losses were reduced most effectively by the theoretical eradication program, followed closely by the realistic eradication program. The base program with a 25 percent increase in program efficiency ranked third in reducing physical losses followed by the current program. All other programs simulated, including the base program with a 25 percent decrease in program efficiency in Class C regions and the three no program scenarios increased physical losses with the sharpest increase occurring under the no program scenario.

(3) *Program costs.* Total discounted program costs over the 30-year period simulated were lowest for the no state-federal program without calfhood vaccination followed by the no state-federal program with calfhood vaccination. Costs accruing to these programs were attributable to producer costs associated with a milk ordinance enforced brucellosis program in dairy cattle and calfhood vaccination. The highest program cost occurred under the base program with a 25 percent decrease in program efficiency in Class C regions as a result of additional secondary epidemiologic tracing, adjacent herd testing, and herd testing as infection increased.

The lowest total program costs associated with alternative programs which were most effective in reducing brucellosis infection and physical losses were almost identical at $1.7 billion for the realistic and theoretical eradication programs as were net declines or savings in program costs at more than $400 million for both programs. The base program with a 25 percent increase in program efficiency in Class C regions and the current program ranked third and fourth, respectively, in total costs and declines in costs for those programs most effective in reducing infection and physical losses. Net declines in total costs accrue from lower program costs attributable to program efficiency resulting in fewer numbers of secondary epidemiologic traces, adjacent herd tests, quarantine and post-quarantine herd tests, and lower handling costs.

(4) *Economic benefits.* The highest positive change in benefits to society, net change in benefits to society, and benefit-cost ratios accrued from the theoretical eradication program, followed closely by the realistic eradication program. The base program with a 25 percent increase in program efficiency and the current program ranked third and fourth, respectively, relative to positive changes in benefits and benefit-cost ratios. The three no state-federal program scenarios and the base program with a 25 percent decrease in program efficiency in Class C regions all produced negative changes in benefits to society, compared to the base program, as well as generating economically unacceptable benefit-cost ratios.

(5) *Equity impact.* Equity analysis revealed that consumers would accrue substantial positive benefits from programs which decrease infection as the eradication programs followed by the base program with a 25 percent increase in efficiency in Class C regions and the current program. Further, consumers would incur large negative benefits or losses from programs which increase infection as the no state-federal program scenarios. Benefits to related agricultural industries parallel those of consumers but at a lower level. Although producers with infected herds may incur catastrophic losses, programs which decrease infection increase supplies of meat and milk, exert a downward pressure on price, creating negative benefits to producers. However, summation of benefits over all sectors revealed that substantial benefits would accrue to society from alternative programs which decrease infection, as the eradication programs, and that large negative benefits would accrue to society from alternative programs which increased infection and physical losses.

Some epidemiologic and economic considerations emanating from this study may be summarized as follows:

(1) The realistic eradication program appears to be the most epidemiologically sound and cost effective program of the alternative programs analyzed since it ranked above other alternative programs, except the theoretical eradication program, in total benefits, net benefits, and benefit-cost ratios. The theoretical eradication program demonstrated that the present "state of the arts" within the U.S. bovine brucellosis program is highly capable of detecting sufficient numbers of infected herds for achieving eradication. Application and/or utilization of current program components at higher efficiency levels through stricter adherence to the requirements of the UM&R, continuation of producer incentives through indemnity payments, along with the incorporation of a depopulation program, would likely result in an annual increase in program costs for an interim period over the program costs currently incurred. However, simulation results of this study, as well as the recent experience of the Canadian Department of Agriculture, suggest that such an approach would be cost effective while leading toward the goal of eradication.

(2) Joint consideration of economic and epidemiologic efficiency is paramount to animal disease programs as bovine brucellosis, given the wide variation in infection among and between states as evidenced by the bovine brucellosis classification system, and as states reach or approach Class Free status. Future cost considerations may suggest that the market cattle surveillance system, depending upon regional classification, be based on a sampling basis provided it meets the requirements of an epidemiologically sound and efficient disease monitoring system.

(3) Research by the NBTC (1978) and Amosson (1983) revealed that contact or adjacent herd testing was an important epidemiologic tool and highly cost effective

in detecting and eliminating brucellosis infection. Results of this study suggest that maximization of adjacent herd testing, post quarantine and post ownership testing, and secondary epidemiologic tracing efficiencies, along with an efficient primary surveillance system as MCI and BRT, are essential in all area classification systems if bovine brucellosis is to be eradicated.

(4) Simulation results again revealed the importance of calfhood vaccination in combating brucellosis infection in high incidence regions as under the no state-federal program scenario where benefits of calfhood vaccination greatly exceeded costs. However, utilization of calfhood vaccination in low incidence regions, where programs are maintained at high efficiency levels, is not cost effective (NBTC 1978 and Amosson 1983). This study further demonstrated that calfhood vaccination, by itself or in the absence of other current program components, will keep brucellosis infection from spreading as rapidly as it would in the absence of vaccination, but calfhood vaccination did not eradicate brucellosis.

(5) Equity analysis revealed that consumers were the major beneficiaries of investments in publicly funded bovine brucellosis programs, which decreased physical losses and increased supplies of meat and milk.

References

Agriculture Canada. "Brucellosis Eradication In Canada-Progress Report." Food Production and Inspection Branch, Canadian Department of Agriculture. March 1985.

Agriculture Canada. "Evaluation of Alternative Brucellosis Programs By Benefit-Cost Analysis." Management Consulting Services, Ottawa, Canada, 1979.

Amosson, Stephen H., Raymond A. Dietrich, and Richard P. Crawford. "Economic and Epidemiologic Analysis of U.S. Bovine Brucellosis Programs - Volume II." Prepared for Veterinary Services, APHIS, U.S. Department of Agriculture, Hyattsville, Maryland, 1985.

Amosson, Stephen H. "Economic and Epidemiologic Implications of National Bovine Brucellosis Programs—A Case Study." Unpublished Ph.D. Dissertation, Texas A&M University, 1983.

Amosson, Stephen H. and Raymond A. Dietrich. "Theoretical Basis and Empirical Implications of the Bovine Brucellosis Market Slaughter Testing Program in the United States." *Preventive Veterinary Medicine*, 3(1984/5) 53-64, 1984.

Anderson, Robert K., David T. Berman, W.T. Berry, John A. Hopkin, and Robert Wise. "Report - National Brucellosis Technical Commission." Prepared for Veterinary Services, APHIS, U.S. Department of Agriculture, Hyattsville, Maryland, 1978.

Beal, Victor C., Jr. "Current Estimated Brucellosis Losses." Veterinary Services, APHIS, U.S. Department of Agriculture, Hyattsville, Maryland, 1984.

Beal, Victor C., Jr. Personal Communication. Veterinary Services, APHIS, U.S. Department of Agriculture, Hyattsville, Maryland, 1985.

Beal, Victor C., Jr. and Harvey A. Kryder, Jr. "Brucellosis Program Analysis." Veterinary Services, APHIS, U.S. Department of Agriculture, 1977.

Becton, Paul. "The National Brucellosis Program of The United States." *Bovine Brucellosis An International Symposium*, eds. Richard P. Crawford and Richard J. Hidalgo, College Station, Texas A&M University Press, 1977.

Collins, G.S. "An Econometric Simulation Model for Evaluating Aggregate Economic Impacts of Technological Change on Major U.S. Field Crops." PhD. Disseration, Texas A&M University, 1980.

Jones, Robert E.L. "Brucellosis Losses and the Feasibility of an Annual Brucellosis Prevention Program for Texas Beef Producers." M.S. Thesis, Texas A&M University, 1979.

Liu, Chun-Ian. "An Economic Impact Evaluation of Government Programs: The Case of Brucellosis Control in the United States." *Southern Journal of Agricultural Economics*. Volume II, Number 1, 1979, pp. 163-168.

U.S. Department of Agriculture. *Cattle*. Washington D.C. 1985.

Acknowledgement

Information in this report is based primarily on "Economic and Epidemiologic Analysis of U.S Bovine Brucellosis Programs—Volume 1," a contract report prepared for Veterinary Services, APHIS, U.S. Department of Agriculture, August 1985, by the Texas Agricultural Experiment Station. Funding for this research was provided by Veterinary Services, APHIS, U.S. Department of Agriculture and the Texas Agricultural Experiment Station. The Brucellosis Policy Advisory Committee aided in the development of alternative bovine brucellosis programs. The Committee was composed of Jack Dahl, rancher, Gackle, North Dakota; Dr. William Cowart, epidemiologist, Elba, Alabama; and Dr. David Hird, epidemiologist, University of California, Davis, California. Helpful suggestions were also provided by Dr. Victor C. Beal, Jr. Veterinary Services, APHIS, U.S. Department of Agriculture, Hyattsville, Maryland.

Appendix 1. Epidemiological factors included in the 1976 APHIS, the 1978 NBTC, and the 1985 Texas Agricultural Experiment Station (TAES) bovine brucellosis analyses

Epidemiological Factors	1976 APHIS	1978 NBTC	1985 TAES
Probability of buying infected animals	X[a]	X	X
All 3 binomial methods include:			
Proportion of herds infected	X	X	X
Number of source herds	X	X	X
Double & triple binomials permits:			
Less than 100% infection in herd	X	X	X
Number of replacements per source herd	X	X	X
Third binomial changes replacement infection:			
Infectiousness of replacements	X	—	X
Age difference in replacements	X	—	X
Quarantined herds	X	NA	NA
1st concentration point testing	X	—	X
Vaccine effect in initiating infection	—	—	X
Incubating infection in replacements	—	—	X
Stratify by herd size	X	X	X
Stratify by year of herd infection	X	X	X
Stratify by dairy and beef	X	X	X
Natural clean-up	X	X	X
Stratified by region (management)	X	X	X
Regional purchase probability	X	X	X
Fence or neighborhood spread	X	X	X
Vaccine effect on infection rate in herd	X	X	X
MCI detection and efficiency	X	X	X
BRT detection and efficiency	X	X	X
Organized clean-up	X	X	X
Depopulation	X	—	X
First point testing effect on MCI:			
Increase traceability	X	X	X
Increase number tested	—	—	X
Differential cull rate for MCI	—	—	X
Stratify quarantined herds	—	X	X
Residual infection	—	X	X
Area testing	—	—	X
Adjacent herd testing	—	—	X
Epidemiological testing	—	—	X
Post quarantine testing	—	—	X

[a]An "X" indicates the factor or activity was included in the study while a "—" indicates the factor or activity was not included in the study. "NA" denotes not applicable.

From: Beal, V.C., Jr. 1983. The use of mathematical models in animal disease program evaluation. Proc. 87th Ann. mtg. U.S. An. Health Assn. 386-402.

Appendix 2. Baseline program - epidemiological summary of U.S. brucellosis program

*** BRUSIM simulation model ***

-- Beef model --- Baseline program --

*** U.S. totals ***

Year	Undetected inf. herds	Quarantined herds	Quarantined inf. cows	Undetected inf. cows	Total inf. cows	Calf loss pounds	Total cost 1982 dol.	Cum. costs discounted
1	21,784.	14,407.	207,101.	130,304.	337,406.	47,028,720.	133,303,856.	168,671,856.
2	20,537.	13,518.	167,230.	116,908.	284,138.	37,540,400.	124,558,768.	320,216,576.
3	19,818.	12,890.	128,252.	105,569.	233,821.	31,545,152.	116,862,464.	456,929,024.
4	20,142.	12,674.	117,031.	107,101.	224,133.	30,700,224.	110,989,136.	581,776,640.
5	19,359.	11,294.	127,096.	105,393.	232,489.	31,781,568.	115,622,416.	706,833,664.
6	17,552.	11,939.	139,314.	95,286.	234,600.	31,787,072.	134,477,216.	846,689,792.
7	15,881.	11,188.	131,728.	84,996.	216,725.	29,539,488.	140,347,072.	987,036,672.
8	13,069.	9,623.	102,472.	65,602.	168,074.	22,555,216.	138,230,832.	1,119,950,850.
9	11,970.	8,170.	84,795.	57,486.	142,281.	19,365,264.	142,549,520.	1,251,745,790.
10	12,479.	5,072.	55,373.	59,551.	114,923.	15,992,933.	114,654,656.	1,353,673,220.
11	12,256.	5,077.	58,339.	58,263.	116,602.	15,919,974.	119,702,128.	1,455,995,140.
12	11,790.	5,116.	57,465.	54,793.	112,258.	15,216,403.	124,136,832.	1,558,026,500.
13	11,406.	4,999.	54,770.	51,944.	106,714.	14,484,265.	123,714,080.	1,655,799,300.
14	11,053.	4,358.	47,434.	50,727.	98,161.	13,307,932.	113,506,400.	1,742,054,660.
15	11,130.	3,912.	44,646.	53,428.	98,074.	13,322,744.	102,217,088.	1,816,743,680.
16	11,055.	3,655.	43,700.	55,635.	99,336.	13,435,901.	98,698,144.	1,886,087,680.
17	11,021.	4,246.	52,131.	55,554.	107,685.	14,548,806.	110,178,016.	1,960,519,940.
18	11,012.	3,810.	47,077.	57,624.	104,701.	14,254,356.	103,568,784.	2,027,796,220.
19	11,240.	4,028.	52,221.	60,661.	112,883.	15,361,806.	107,955,744.	2,095,225,090.
20	11,376.	3,976.	53,075.	63,823.	116,898.	15,971,345.	109,113,968.	2,160,755,970.
21	11,366.	4,846.	65,548.	63,258.	128,806.	17,562,400.	128,240,176.	2,234,811,390.
22	10,880.	5,272.	67,299.	58,348.	125,647.	17,169,632.	140,270,000.	2,312,698,370.
23	10,890.	4,195.	54,153.	60,346.	114,499.	15,718,087.	119,229,360.	2,376,355,840.
24	10,772.	3,868.	51,940.	61,283.	113,223.	15,361,629.	113,998,112.	2,434,879,230.
25	10,869.	4,046.	55,584.	62,283.	117,867.	16,018,961.	117,230,416.	2,492,747,260.
26	10,862.	4,036.	55,863.	63,146.	119,009.	16,234,174.	118,566,896.	2,549,024,000.
27	11,086.	4,001.	56,981.	66,345.	123,326.	16,877,456.	118,172,256.	2,602,956,290.
28	11,034.	4,159.	60,151.	66,908.	127,059.	17,323,040.	123,142,384.	2,656,995,330.
29	11,558.	4,234.	63,439.	72,738.	136,177.	18,789,360.	123,990,304.	2,709,313,540.
30	11,887.	4,483.	70,008.	78,183.	148,192.	20,518,688.	131,335,120.	2,762,599,680.

Appendix 3. Baseline program - epidemiological summary of U.S. Brucellosis program

*** BRUSIM simulation model ***

-- Dairy model --- Baseline program --

** U.S. totals **

Year	Undetected Inf. herds	Quarantined herds	Quarantined inf. cows	Undetected inf. cows	Total inf. cows	Calf loss pounds	Milk loss pounds	Total cost 1982 dol.	Cum. costs discounted
1	218.	1,445.	26,317.	1,449.	27,766.	578,558.	61,919,312.	39,613,424.	50,123,600.
2	170.	1,213.	15,712.	1,191.	16,902.	377,101.	38,254,592.	34,088,496.	91,597,456.
3	144.	1,162.	13,526.	939.	14,465.	316,109.	32,785,136.	33,300,176.	130,553,936.
4	130.	1,075.	11,952.	855.	12,807.	282,020.	29,076,144.	32,507,952.	167,120,944.
5	114.	843.	10,782.	708.	11,490.	252,492.	26,266,384.	36,026,112.	206,086,768.
6	62.	720.	9,806.	480.	10,285.	221,595.	23,810,128.	33,307,696.	240,726,768.
7	51.	487.	7,532.	371.	7,902.	169,297.	18,793,584.	33,056,912.	273,783,552.
8	42.	365.	5,088.	272.	5,359.	114,008.	12,669,701.	29,443,840.	302,094,848.
9	38.	297.	3,961.	238.	4,199.	89,554.	9,867,967.	26,345,056.	326,452,224.
10	38.	254.	3,507.	236.	3,743.	79,722.	8,726,738.	21,749,840.	345,787,648.
11	33.	221.	3,074.	196.	3,271.	68,896.	7,624,870.	22,102,912.	364,681,216.
12	30.	216.	3,002.	176.	3,178.	67,359.	7,396,574.	23,728,096.	384,183,808.
13	29.	215.	2,991.	171.	3,162.	67,407.	7,339,524.	24,231,632.	403,334,400.
14	29.	212.	2,984.	170.	3,155.	67,376.	7,316,455.	24,027,776.	421,593,344.
15	28.	214.	3,010.	161.	3,171.	67,729.	7,357,225.	25,789,200.	440,437,248.
16	27.	211.	2,966.	158.	3,124.	66,928.	7,241,006.	25,909,696.	458,640,896.
17	27.	202.	2,902.	164.	3,066.	65,698.	7,092,317.	24,085,296.	474,912,000.
18	27.	220.	3,094.	152.	3,247.	69,470.	7,496,022.	28,038,368.	493,125,120.
19	27.	205.	2,939.	163.	3,103.	66,689.	7,142,176.	24,501,552.	508,428,544.
20	27.	214.	3,083.	159.	3,242.	69,393.	7,448,806.	26,420,416.	524,295,936.
21	28.	209.	3,074.	171.	3,245.	69,657.	7,419,056.	24,378,400.	538,373,632.
22	29.	214.	3,178.	174.	3,352.	71,761.	7,648,344.	24,529,776.	551,994,112.
23	29.	218.	3,222.	171.	3,393.	72,648.	7,731,643.	25,354,544.	565,530,880.
24	27.	214.	3,156.	163.	3,320.	71,085.	7,564,681.	26,161,424.	578,961,408.
25	26.	218.	3,178.	152.	3,330.	71,445.	7,584,360.	28,395,888.	592,978,176.
26	26.	220.	3,183.	149.	3,332.	71,748.	7,572,875.	29,098,320.	606,789,376.
27	26.	219.	3,179.	149.	3,328.	71,717.	7,549,127.	28,813,120.	619,939,072.
28	26.	217.	3,189.	151.	3,340.	71,968.	7,561,498.	28,356,128.	632,382,464.
29	26.	219.	3,233.	152.	3,385.	72,922.	7,647,667.	28,533,600.	644,422,144.
30	26.	213.	3,216.	161.	3,378.	72,782.	7,609,882.	26,552,624.	655,195,136.

Appendix 4. Baseline program—brucellosis program component test summary

*************** BRUSIM simulation model ***************

--------------- Beef model - - - Baseline program ---------------

*************** U.S. totals ***************

Year	FPC cows tested	SPT cows tested	MCI herds quarntd.	MCI reactors detected	Area Test herds tested	Area Test herds quarntd.	Non-Primary Sur. Herds tested	Non-Primary Sur. Herds quarntd.	Heifers vaccinatd.	On farm tests
1	3,003,894.	6,666,029.	9,342.	59,395.	13,886.	49.	124,958.	3,900.	2,916,407.	7,315,604.
2	3,124,041.	6,501,146.	7,831.	48,363.	32,447.	174.	123,957.	3,423.	2,916,407.	6,477,280.
3	3,367,423.	5,562,879.	6,336.	36,521.	39,217.	308.	124,533.	3,279.	3,080,424.	5,913,792.
4	3,427,235.	3,886,849.	5,215.	30,715.	22,774.	661.	125,948.	3,430.	3,923,985.	5,442,857.
5	3,297,318.	3,566,368.	5,183.	29,158.	13,714.	704.	140,007.	4,394.	4,519,871.	5,560,188.
6	3,952,536.	4,347,426.	5,754.	32,169.	9,422.	388.	147,203.	5,046.	5,458,767.	6,209,907.
7	4,037,473.	4,928,607.	5,680.	31,834.	8,871.	393.	148,662.	4,701.	6,013,894.	6,302,816.
8	4,088,851.	6,786,816.	4,922.	26,206.	6,860.	280.	147,178.	3,997.	6,352,222.	5,473,912.
9	5,012,588.	6,848,591.	4,194.	26,430.	5,183.	143.	145,728.	3,560.	7,250,514.	5,108,438.
10	3,860,068.	6,648,802.	3,217	20,895.	0.	0.	132,994.	1,536.	6,393,669.	3,914,084.
11	4,098,070.	7,239,200.	3,425.	22,123.	0.	0.	132,994.	1,584.	6,578,440.	3,980,149.
12	4,291,049.	8,198,268.	3,531.	22,420.	0.	0.	132,994.	1,511.	6,714,604.	3,923,670.
13	4,388,993.	8,331,908.	3,468.	21,998.	0.	0.	132,994.	1,442.	6,644,099.	3,830,775.
14	3,772,408	7,321,889.	2,897.	17,905.	0.	0.	132,994.	1,355.	6,590,942.	3,512,463.
15	3,357,374.	5,766,646.	2,507.	15,808.	0.	0.	132,994.	1,334.	6,488,120.	3,417,937.
16	2,951,022.	5,250,658.	2,281.	14,017.	0.	0.	132,994.	1,328.	6,654,856.	3,362,187.
17	3,642,275.	6,325,249.	2,864.	18,086.	0.	0.	132,994.	1,371.	6,740,698.	3,697,340.
18	3,095,137.	5,504,034.	2,438.	14,931.	0.	0.	132,994.	1,297.	6,898,424.	3,564,850.
19	3,358,415.	5,411,802.	2,657.	16,822.	0.	0.	132,994.	1,341.	6,989,476.	3,800,690.
20	3,183,670.	5,312,989.	2,601.	16,109.	0.	0.	132,994.	1,327.	7,273,238.	3,887,735.
21	4,133,521.	7,024,462.	3,453.	21,935.	0.	0.	132,994.	1,375.	7,483,430.	4,405,376.
22	4,680,864.	9,034,539.	3,881.	24,178.	0.	0.	132,994.	1,310.	7,713,160.	4,501,848.
23	3,633,678.	6,658,590.	2,860.	17,441.	0.	0.	132,994.	1,201.	7,603,630.	4,051,625.
24	3,255,599.	6,052,644.	2,596.	15,609.	0.	0.	132,994.	1,207.	7,643,163.	3,894,050.
25	3,523,003.	6,104,719.	2,786.	17,238.	0.	0.	132,994.	1,221.	7,648,505.	4,058,801.
26	3,467,525.	6,200,013.	2,782.	16,946.	0.	0.	132,994.	1,200.	7,806,058.	4,105,172.
27	3,432,045.	5,703,507.	2,745.	17,013.	0.	0.	132,944.	1,204.	7,896,604.	4,206,489.
28	3,515,297.	6,299,585.	2,910.	17,670.	0.	0.	132,944.	1,206.	8,131,127.	4,324,785.
29	3,650,377.	5,452,996.	2,960.	18,875.	0.	0.	132,994.	1,223.	8,218,123.	4,590,867.
30	3,726,419.	5,816,334.	3,184.	20,043.	0.	0.	132,994.	1,259.	8,664,361.	4,916,648.

Appendix 5. Baseline program—brucellosis program component test summary

** BRUSIM simulation model **

-- Dairy model - - - Baseline program --

** U.S. totals **

Year	FPC cows tested	SPT cows tested	MCI herds quarntd.	MCI reactors detected	Area Test herds tested	Area Test herds quarntd.	Non-Primary Sur. herds tested	Non-Primary Sur. herds quarnted.	Heifers vaccinatd.	On farm tests
1	791,794.	3,067,230.	1,096.	9,552.	0.	0.	39,196.	232.	924,140.	2,044,097.
2	845,845.	2,939,561.	813.	5,433	0.	0.	39,170.	171.	924,140.	1,688,347.
3	935,108.	2,929,904.	711.	4,588.	0.	0.	39,054.	143.	977,521.	1,582,827.
4	1,008,592.	2,670,792.	621.	3,777.	0.	0.	39,124.	138.	1,165,404.	1,499,012.
5	1,204,736.	3,490,203.	582.	4,240.	0.	0.	41,425.	186.	1,315,949.	1,405,792.
6	1,094,430.	2,869,817.	517.	3,265.	0.	0.	41,730.	189.	1,409,657.	1,374,749.
7	1,018,882.	3,265,128.	384.	2,558.	0.	0.	41,576.	185.	1,535,242.	1,204,564.
8	890,064.	3,328,258.	295.	1,715.	0.	0.	41,406.	136.	1,501,939.	949,459.
9	804,081.	2,688,762.	248.	1,240.	0.	0.	41,198.	100.	1,569,360.	875,140.
10	569,207.	2,132,424.	229.	831.	0.	0.	40,645.	38.	1,300,107.	833,031.
11	602,246.	2,257,440.	201.	763.	0.	0.	40,645.	33.	1,308,427.	816,395.
12	695,538.	2,611,121.	198.	850.	0.	0.	40,645.	31.	1,316,800.	820,926.
13	721,273.	2,708,088.	197.	874.	0.	0.	40,645.	30.	1,325,095.	825,605.
14	706,586.	2,652,286.	194.	851.	0.	0.	40,645.	30.	1,333,575.	827,817.
15	802,994.	3,013,073.	196.	962.	0.	0.	40,645.	30.	1,342,108.	839,346.
16	806,384.	3,025,698.	193.	944.	0.	0.	40,645.	28.	1,352,172.	843,973.
17	700,180.	2,623,110.	184.	801.	0.	0.	40,645.	27.	1,362,314.	840,131.
18	914,401.	3,434,496.	203.	1,096.	0.	0.	40,645.	29.	1,372,530.	866,738.
19	712,815.	2,670,536.	186.	814.	0.	0.	40,645.	26.	1,382,824.	855,292.
20	813,372.	3,051,282.	197.	963.	0.	0.	40,645.	27.	1,393,194.	871,656.
21	693,191.	2,595,732.	192.	812.	0.	0.	40,645.	24.	1,403,643.	868,794.
22	694,108.	2,598,978.	197.	843.	0.	0.	40,645.	27.	1,414,170.	878,219.
23	734,748.	2,752,721.	201.	899.	0.	0.	40,645.	28.	1,424,776.	888,658.
24	778,132.	2,916,855.	197.	920.	0.	0.	40,645.	26.	1,435,461.	893,882.
25	899,692.	3,377,172.	202.	1,056.	0.	0.	40,645.	26.	1,446,226.	908,069.
26	934,170.	3,507,557.	203.	1,089.	0.	0.	40,645.	26.	1,457,072.	917,338.
27	916,095.	3,438,838.	202.	1,061.	0.	0.	40,645.	25.	1,468,000.	922,375.
28	884,902.	3,320,422.	201.	1,025.	0.	0.	40,645.	25.	1,479,009.	926,700.
29	888,638.	3,334,334.	203.	1,040.	0.	0.	40,645.	26.	1,490,100.	934,846.
30	771,601.	2,890,679.	197.	901.	0.	0.	40,645.	25.	1,501,276.	932,518.

Appendix 6. Baseline program - brucellosis livestock producer expenditures

*** BRUSIM simulation model ***

--- Beef model --- Baseline program ---

** U.S. totals **

Year	Producer MCI test costs	Producer area test costs	Producer post quar. costs	Producer private costs	Producer sec. epi. costs	Producer adj. test costs	Producer vaccinatn. costs	Producer quarntd. costs	Producer total cost 1982 dol.
1	18,302,656.	804,593.	80,696.	2,906,992.	37,495.	130,695.	9,430,154.	8,840,849.	40,534,096.
2	17,230,256.	1,297,595.	96,646.	2,906,992.	31,046.	103,952.	9,430,154.	8,072,120.	39,168,704.
3	16,295,895.	1,494,631.	114,745.	2,906,992.	32,636.	111,808.	9,332,458.	7,470,615.	37,759,744.
4	14,475,057.	854,752.	129,305.	3,045,653.	61,226.	168,436.	10,723,407.	7,331,381.	36,789,168.
5	14,102,351.	676,093.	298,835.	3,464,741.	134,737.	352,975.	11,226,306.	6,429,410.	36,685,408.
6	16,887,152.	729,038.	356,188.	3,737,077.	193,209.	520,630.	13,529,154.	6,954,224.	42,906,640.
7	17,799,984.	749,711.	429,144.	4,055,824.	201,697.	526,189.	15,008,331.	6,608,489.	45,379,328.
8	19,506,672.	526,883.	371,875.	3,946,570.	172,256.	439,268.	16,393,999.	5,450,886.	46,808,368.
9	21,602,944.	468,142.	344,794.	4,106,402.	162,848.	402,656.	18,712,320.	4,835,383.	50,635,472.
10	18,253,248.	0.	0.	4,225,071.	0.	0.	16,500,968.	3,465,665.	42,444,928.
11	19,585,088.	0.	0.	4,312,520.	0.	0.	16,977,824.	3,473,137.	44,348,576.
12	21,048,656.	0.	0.	4,267,237.	0.	0.	17,329,248.	3,415,492.	46,060,640.
13	21,375,536.	0.	0.	4,233,093.	0.	0.	17,147,280.	3,297,237.	46,053,152.
14	18,511,904.	0.	0.	4,167,054.	0.	0.	17,010,096.	2,852,330.	42,541,376.
15	15,760,784.	0.	0.	4,274,140.	0.	0.	16,744,730.	2,654,742.	39,434,368.
16	14,152,131.	0.	0.	4,329,271.	0.	0.	17,175,040.	2,532,217.	38,188,656.
17	17,306,544.	0.	0.	4,430,569.	0.	0.	17,396,592.	3,003,158.	42,136,864.
18	14,925,301.	0.	0.	4,489,047.	0.	0.	17,803,648.	2,771,544.	39,989,520.
19	15,659,332.	0.	0.	4,671,293.	0.	0.	18,038,640.	3,057,721.	41,426,976.
20	15,147,014.	0.	0.	4,806,289.	0.	0.	18,770,992.	3,126,990.	41,851,264.
21	19,765,792.	0.	0.	4,953,828.	0.	0.	19,313,440.	3,882,233.	47,915,296.
22	23,326,256.	0.	0.	4,883,479.	0.	0.	19,906,352.	4,092,879.	52,208,976.
23	17,792,624.	0.	0.	4,908,871.	0.	0.	19,623,648.	3,348,360.	45,673,488.
24	16,068,894.	0.	0.	4,912,300.	0.	0.	19,725,696.	3,098,724.	43,805,584.
25	16,932,816.	0.	0.	5,013,483.	0.	0.	19,739,472.	3,315,312.	45,001,072.
26	16,915,136.	0.	0.	5,071,637.	0.	0.	20,146,096.	3,361,522.	45,494,400.
27	16,355,465.	0.	0.	5,222,257.	0.	0.	20,379,776.	3,455,662.	45,413,120.
28	17,275,712.	0.	0.	5,278,130.	0.	0.	20,985,056.	3,623,562.	47,162,480.
29	16,897,136.	0.	0.	5,564,725.	0.	0.	21,209,568.	3,921,002.	47,592,400.
30	17,686,224.	0.	0.	5,806,781.	0.	0.	22,361,232.	4,328,611.	50,182,848.

Appendix 7. Baseline program - brucellosis livestock producer expenditures

** BRUSIM simulation model **
-- Dairy model --- Baseline program --
** U.S. totals **

Year	Producer MCI test costs	Producer area test costs	Producer post quar. costs	Producer private costs	Producer sec. epi. costs	Producer adj. test costs	Producer vaccinatn. costs	Producer quarntd. costs	Producer total cost 1982 dol.
1	5,283,068.	0.	9,868.	466,331.	2,798.	0.	3,204,193.	582,092.	9,548,355.
2	5,202,969.	0.	6,737.	466,331.	2,418.	1,930.	3,204,193.	466,140.	9,350,720.
3	5,380,870.	0.	4,543.	466,331.	1,432.	1,356.	3,396,355.	445,609.	9,696,497.
4	5,294,076.	0.	5,916.	487,781.	2,454.	1,573.	3,946,667.	398,259.	10,136,729.
5	6,591,597.	0.	12,133.	518,188.	4,079.	5,905.	4,333,040.	312,987.	11,777,929.
6	5,688,954.	0.	13,011.	552,176.	5,439.	9,120.	4,618,826.	271,596.	11,159,128.
7	5,883,100.	0.	13,117.	554,199.	5,673.	11,614.	4,995,891.	175,699.	11,639,294.
8	5,596,793.	0.	7,801.	491,552.	3,745.	8,127.	5,004,367.	108,335.	11,220,716.
9	4,737,007.	0.	5,572.	480,492.	2,772.	4,843.	5,229,012.	85,125.	10,544,822.
10	3,600,813.	0.	0.	483,566.	0.	0.	4,331,873.	69,346.	8,485,606.
11	3,803,643.	0.	0.	486,660.	0.	0.	4,359,596.	60,315.	8,710,221.
12	4,389,156.	0.	0.	489,726.	0.	0.	4,387,494.	59,477.	9,325,861.
13	4,549,964.	0.	0.	492,859.	0.	0.	4,415,133.	59,713.	9,517,673.
14	4,457,130.	0.	0.	496,013.	0.	0.	4,443,385.	59,296.	9,455,830.
15	5,058,165.	0.	0.	499,732.	0.	0.	4,471,819.	61,224.	10,090,946.
16	5,079,064.	0.	0.	503,480.	0.	0.	4,505,357.	61,101.	10,149,007.
17	4,411,532.	0.	0.	507,256.	0.	0.	4,539,144.	58,351.	9,516,289.
18	5,759,491.	0.	0.	511,060.	0.	0.	4,573,186.	64,716.	10,908,458.
19	4,491,794.	0.	0.	514,892.	0.	0.	4,607,483.	60,181.	9,674,356.
20	5,124,899.	0.	0.	518,753.	0.	0.	4,642,038.	63,500.	10,349,195.
21	4,369,844.	0.	0.	522,643.	0.	0.	4,676,852.	61,451.	9,630,795.
22	4,376,730.	0.	0.	526,563.	0.	0.	4,711,926.	63,034.	9,678,264.
23	4,632,306.	0.	0.	530,512.	0.	0.	4,747,264.	64,912.	9,974,998.
24	4,903,258.	0.	0.	534,490.	0.	0.	4,782,863.	64,979.	10,285,598.
25	5,666,589.	0.	0.	538,498.	0.	0.	4,818,734.	67,708.	11,091,536.
26	5,883,121.	0.	0.	542,537.	0.	0.	4,854,874.	69,207.	11,349,745.
27	5,769,441.	0.	0.	546,605.	0.	0.	4,891,283.	69,361.	11,276,692.
28	5,573,603.	0.	0.	550,704.	0.	0.	4,927,968.	69,193.	11,121,472.
29	5,597,593.	0.	0.	554,834.	0.	0.	4,964,925.	70,213.	11,187,571.
30	4,862,267.	0.	0.	558,995.	0.	0.	5,002,159.	68,096.	10,491,522.

Appendix 8. Baseline program - state and federal brucellosis expenditures

*** BRUSIM simulation model ***

--- Beef model --- Baseline program ---

** U.S. totals **

Year	MCI sur. cost	Init. MCI farm test cost	Init. area farm test cost	Herd depop. & indemnity payments	Init. test non-prim. cost	Vaccinatn. cost	Retest quar. herd cost	Total cost 1982 dollars	Total cost nominal dollars
1	24,671,008.	12,807,521.	3,984,545.	12,426,105.	9,113,678.	3,440,678.	26,326,336.	92,769,824.	53,919,696.
2	24,491,120.	8,530,579.	6,233,610.	10,033,814.	9,041,159.	3,440,678.	23,619,216.	85,390,128.	53,351,280.
3	22,464,592.	6,673,007.	7,105,279.	7,695,119.	9,149,476.	5,124,773.	20,890,576.	79,102,784.	52,914,064.
4	18,224,240.	5,867,568.	4,106,523.	7,021,914.	9,843,050.	9,336,659.	19,800,128.	74,200,032.	54,756,720.
5	17,058,176.	6,637,183.	3,639,717.	7,625,795.	12,717,496.	13,402,201.	17,856,512.	78,937,072.	66,164,144.
6	20,659,504.	7,572,174.	4,631,655.	8,358,870.	14,882,856.	16,275,484.	19,190,144.	91,570,656.	85,252,448.
7	22,353,792.	7,803,568.	4,812,034.	7,903,718.	16,079,997.	17,690,640.	18,324,064.	94,967,776.	94,967,776.
8	27,401,616.	6,985,916.	3,321,818.	6,148,324.	15,071,886.	17,487,792.	15,005,161.	91,422,496.	94,632,336.
9	29,554,528.	6,224,140.	3,052,999.	5,087,717.	15,090,397.	19,805,856.	13,098,498.	91,914,112.	95,141,264.
10	25,642,656.	5,378,010.	0.	3,322,351.	11,167,377.	17,350,256.	9,349,201.	72,209,808.	74,745,168.
11	27,682,384.	5,742,108.	0.	3,500,346.	11,398,517.	17,851,664.	9,178,624.	75,353,632.	77,999,296.
12	30,534,432.	5,760,510.	0.	3,447,914.	11,270,970.	18,187,360.	8,875,101.	78,076,256.	80,817,552.
13	31,095,520.	5,604,075.	0.	3,286,222.	11,180,793.	17,996,384.	8,497,994.	77,660,960.	80,387,680.
14	27,134,736.	4,767,659.	0.	2,846,019.	11,006,361.	17,852,400.	7,357,959.	70,965,104.	73,456,720.
15	21,192,640.	4,185,618.	0.	2,678,787.	10,899,147.	17,152,656.	6,673,983.	62,782,816.	64,987,136.
16	19,044,976.	3,962,326.	0.	2,622,022.	11,018,279.	17,539,376.	6,322,630.	60,509,584.	62,634,096.
17	23,263,040.	4,895,898.	0.	3,127,854.	11,303,790.	17,935,184.	7,515,497.	68,041,248.	70,430,208.
18	19,967,712.	4,337,652.	0.	2,824,593.	11,424,918.	18,181,312.	6,843,171.	63,579,344.	65,811,648.
19	20,433,984.	4,817,288.	0.	3,133,270.	11,917,956.	18,597,104.	7,629,222.	66,528,800.	68,864,672.
20	19,812,416.	4,862,589.	0.	3,184,477.	12,262,368.	19,352,128.	7,788,808.	67,262,768.	69,624,384.
21	27,167,616.	6,346,782.	0.	3,932,865.	13,059,915.	20,208,992.	9,608,781.	80,324,944.	83,145,184.
22	33,504,320.	6,780,527.	0.	4,037,956.	12,874,451.	20,829,392.	10,034,502.	88,061,104.	91,152,992.
23	24,049,680.	5,273,424.	0.	3,249,177.	12,524,089.	20,231,216.	8,228,369.	73,555,936.	76,138,496.
24	21,757,248.	4,836,150.	0.	3,116,401.	12,532,834.	20,336,400.	7,613,568.	70,192,608.	72,657,088.
25	22,468,880.	5,193,476.	0.	3,335,022.	12,791,001.	20,350,592.	8,090,467.	72,229,424.	74,765,424.
26	22,577,616.	5,247,331.	0.	3,351,788.	12,939,360.	20,769,808.	8,186,672.	73,072,560.	75,638,160.
27	21,300,144.	5,303,685.	0.	3,418,871.	13,323,644.	21,010,736.	8,402,141.	72,759,200.	75,313,824.
28	22,922,864.	5,580,019.	0.	3,609,061.	13,466,187.	21,634,736.	8,767,109.	75,979,952.	78,647,648.
29	21,173,104.	5,894,062.	0.	3,806,320.	14,197,386.	21,866,208.	9,460,912.	76,397,968.	79,080,320.
30	22,217,632.	6,458,530.	0.	4,200,502.	14,814,952.	23,053,520.	10,407,236.	81,152,336.	84,001,616.

Appendix 9. Baseline Program—state and federal brucellosis expenditures

** BRUSIM simulation model **

-- Dairy model - - - Baseline program --

** U.S. totals **

Year	MCI sur. cost	Init. MCI. farm test cost	Init. area farm test cost	Herd depop. & indemnity payments	Init. test non-prim. cost	Vaccinatn. cost	Retest quar. herd cost	Total cost 1982 dollars	Total cost nominal dollars
1	9,295,548.	2,847,437.	0.	6,579,338.	3,817,453.	579,271.	6,946,178.	30,065,168.	17,474,528.
2	9,092,134.	1,872,132.	0.	3,927,893.	3,752,154.	571,092.	5,522,528.	24,737,920.	15,456,130.
3	9,223,356.	1,500,624.	0.	3,381,580.	3,683,236.	586,612.	5,228,384.	23,603,776.	15,789,246.
4	8,670,310.	1,392,215.	0.	2,988,085.	3,863,928.	933,942.	4,522,849.	22,371,312.	16,509,183.
5	11,047,120.	1,332,340.	0.	2,695,517.	4,273,810.	1,341,852.	3,557,733.	24,248,352.	20,324,704.
6	9,283,105.	1,224,084.	0.	2,451,412.	4,611,411.	1,500,169.	3,078,525.	22,148,704.	20,620,464.
7	10,065,455.	1,062,232.	0.	1,882,980.	4,681,439.	1,722,350.	2,003,328.	21,417,760.	21,417,760.
8	9,621,937.	721,634.	0.	1,271,927.	3,981,519.	1,400,231.	1,225,973.	18,223,216.	18,863,024.
9	7,953,895.	642,734.	0.	990,256.	3,793,387.	1,460,052.	960,020.	15,800,346.	16,355,100.
10	6,145,539.	636,731.	0.	876,757.	3,619,595.	1,209,551.	776,107.	13,264,288.	13,730,003.
11	6,500,742.	599,300.	0.	768,593.	3,641,715.	1,212,360.	670,013.	13,392,729.	13,862,952.
12	7,510,423.	612,786.	0.	750,580.	3,662,681.	1,213,594.	652,222.	14,402,291.	14,907,958.
13	7,789,128.	616,271.	0.	747,779.	3,686,117.	1,221,239.	653,529.	14,714,069.	15,230,685.
14	7,629,006.	608,920.	0.	746,074.	3,709,704.	1,229,054.	649,287.	14,572,048.	15,083,675.
15	8,667,394.	633,429.	0.	752,383.	3,737,524.	1,236,917.	670,741.	15,698,393.	16,249,567.
16	8,703,767.	633,583.	0.	741,430.	3,765,552.	1,246,194.	670,265.	15,760,794.	16,314,164.
17	7,548,005.	605,402.	0.	725,378.	3,793,790.	1,255,539.	640,964.	14,569,083.	15,080,607.
18	9,877,723.	683,647.	0.	773,609.	3,822,241.	1,264,957.	707,887.	17,130,064.	17,731,504.
19	7,684,418.	622,337.	0.	734,817.	3,850,905.	1,274,442.	660,369.	14,827,295.	15,347,888.
20	8,777,723.	663,896.	0.	770,675.	3,879,781.	1,284,000.	695,264.	16,071,343.	16,635,613.
21	7,469,902.	634,267.	0.	768,436.	3,908,878.	1,293,629.	672,571.	14,747,690.	15,265,487.
22	7,479,349.	647,439.	0.	794,518.	3,938,190.	1,303,332.	688,757.	14,851,587.	15,373,030.
23	7,920,891.	663,415.	0.	805,535.	3,967,723.	1,313,105.	708,993.	15,379,669.	15,919,655.
24	8,392,275.	662,869.	0.	789,070.	3,997,475.	1,322,952.	711,305.	15,875,953.	16,433,363.
25	9,714,034.	694,356.	0.	794,447.	4,027,459.	1,332,874.	741,315.	17,304,480.	17,912,048.
26	10,088,526.	705,949.	0.	795,777.	4,057,658.	1,342,870.	757,958.	17,748,736.	18,371,888.
27	9,870,179.	701,881.	0.	794,798.	4,082,505.	1,327,711.	759,491.	17,536,560.	18,152,272.
28	9,531,043.	697,948.	0.	797,308.	4,113,122.	1,337,668.	757,688.	17,234,768.	17,839,888.
29	9,571,040.	706,746.	0.	808,348.	4,143,967.	1,347,699.	768,353.	17,346,144.	17,955,168.
30	8,300,113.	678,738.	0.	804,048.	4,175,041.	1,357,807.	745,474.	16,061,225.	16,625,141.

Appendix 10. Baseline program—non-primary surveillance component summary

*** BRUSIM Simulation Model ***

-- Beef model - - - baseline program --

** U.S. totals **

Year	Adjacent herds tested	Adjacent herds quarntd.	Post Quar. herds tested	Post Quar. herds quarntd.	Private herds tested	Private herds quarntd.	Sec. Epi. herds tested	Sec. Epi. herds quarntd.	Non-Primary Sur. Herds tested	Non-Primary Sur. Herds quarntd.
1	2,785.	466.	1,422.	157.	119,948.	3,140.	803.	137.	124,958.	3,900.
2	2,112.	356.	1,267.	134.	119,948.	2,824.	630.	109.	123,957.	3,423.
3	2,397.	409.	1,504.	155.	119,948.	2,597.	684.	118.	124,533.	3,279.
4	3,251.	565.	1,694.	174.	119,948.	2,503.	1,056.	188.	125,948.	3,430.
5	6,197.	1,099.	3,462.	350.	128,246.	2,573.	2,101.	372.	140,007.	4,394.
6	8,789.	1,530.	4,610.	455.	130,893.	2,561.	2,911.	501.	147,203.	5,046.
7	8,258.	1,418.	5,119.	479.	132,458.	2,324.	2,827.	481.	148,662.	4,701.
8	7,001.	1,148.	4,729.	435.	132,994.	2,011.	2,454.	404.	147,178.	3,997.
9	6,226.	1,019.	4,250.	381.	132,994.	1,786.	2,259.	374.	145,728.	3,560.
10	0.	0.	0.	0.	132,994.	1,536.	0.	0.	132,994.	1,536.
11	0.	0.	0.	0.	132,994.	1,584.	0.	0.	132,994.	1,584.
12	0.	0.	0.	0.	132,994.	1,511.	0.	0.	132,994.	1,511.
13	0.	0.	0.	0.	132,994.	1,442.	0.	0.	132,994.	1,442.
14	0.	0.	0.	0.	132,994.	1,355.	0.	0.	132,994.	1,355.
15	0.	0.	0.	0.	132,994.	1,334.	0.	0.	132,994	1,334.
16	0.	0.	0.	0.	132,994.	1,328.	0.	0.	132,994.	1,328.
17	0.	0.	0.	0.	132,994.	1,371.	0.	0.	132,994.	1,371.
18	0.	0.	0.	0.	132,994.	1,297.	0.	0.	132,994.	1,297
19	0.	0.	0.	0.	132,994.	1,341.	0.	0.	132,994.	1,341.
20	0.	0.	0.	0.	132,994.	1,327.	0.	0.	132,994.	1,327.
21	0.	0.	0.	0.	132,994.	1,375.	0.	0.	132,994.	1,375.
22	0.	0.	0.	0.	132,994.	1,310.	0.	0.	132,994.	1,310.
23	0.	0.	0.	0.	132,994.	1,201.	0.	0.	132,994.	1,201.
24	0.	0.	0.	0.	132,994.	1,207.	0.	0.	132,994.	1,207.
25	0.	0.	0.	0.	132,994.	1,221.	0.	0.	132,994.	1,221.
26	0.	0.	0.	0.	132,994.	1,200	0.	0.	132,994.	1,200.
27	0.	0.	0.	0.	132,994.	1,204.	0.	0.	132,994.	1,204.
28	0.	0.	0.	0.	132,994.	1,206.	0.	0.	132,994.	1,206.
29	0.	0.	0.	0.	132,994.	1,223.	0.	0.	132,994.	1,223.
30	0.	0.	0.	0.	132,994.	1,259.	0.	0.	132,994.	1,259.

Appendix 11. Baseline program—non-primary surveillance component summary

** BRUSIM simulation model **
-- Dairy model - - - baseline program --
** U.S. totals **

Year	Adjacent herds tested	Adjacent herds quarntd.	Post Quar. herds tested	Post Quar. herds quarntd.	Private herds tested	Private herds quarntd.	Sec. Epi. herds tested	Sec. Epi. herds quarntd.	Non-Primary Sur. Herds tested	Non-Primary Sur. Herds quarntd.
1	0.	0.	257.	14.	38,820.	198.	119.	20.	39,196.	232.
2	93.	8.	165.	10.	38,820.	138.	92.	15.	39,170.	171.
3	66.	6.	110.	7.	38,820.	121.	57.	9.	39,054.	143.
4	75.	7.	134.	10.	38,820.	106.	94.	16.	39,124.	138.
5	295.	31.	311.	24.	40,662.	107.	157.	24.	41,425.	186.
6	389.	44.	340.	22.	40,797.	92.	205.	30.	41,730.	189.
7	458.	60.	324.	22.	40,590.	74.	205.	30.	41,576.	185.
8	369.	43.	237.	14.	40,645.	58.	155.	21.	41,406.	136.
9	251.	26.	186.	11.	40,645.	48.	117.	15.	41,198.	100.
10	0.	0.	0.	0.	40,645.	38.	0.	0.	40,645.	38.
11	0.	0.	0.	0.	40,645.	33.	0.	0.	40,645.	33.
12	0.	0.	0.	0.	40,645.	31.	0.	0.	40,645.	31.
13	0.	0.	0.	0.	40,645.	30.	0.	0.	40,645.	30.
14	0.	0.	0.	0.	40,645.	30.	0.	0.	40,645.	30.
15	0.	0.	0.	0.	40,645.	30.	0.	0.	40,645.	30.
16	0.	0.	0.	0.	40,645.	28.	0.	0.	40,645.	28.
17	0.	0.	0.	0.	40,645.	27.	0.	0.	40,645.	27.
18	0.	0.	0.	0.	40,645.	29.	0.	0.	40,645.	29.
19	0.	0.	0.	0.	40,645.	26.	0.	0.	40,645.	26.
20	0.	0.	0.	0.	40,645.	27.	0.	0.	40,645.	27.
21	0.	0.	0.	0.	40,645.	24.	0.	0.	40,645.	24.
22	0.	0.	0.	0.	40,645.	27.	0.	0.	40,645.	27.
23	0.	0.	0.	0.	40,645.	28.	0.	0.	40,645.	28.
24	0.	0.	0.	0.	40,645.	26.	0.	0.	40,645.	26.
25	0.	0.	0.	0.	40,645.	26.	0.	0.	40,645.	26.
26	0.	0.	0.	0.	40,645.	26.	0.	0.	40,645.	26.
27	0.	0.	0.	0.	40,645.	25.	0.	0.	40,645.	25.
28	0.	0.	0.	0.	40,645.	25.	0.	0.	40,645.	25.
29	0.	0.	0.	0.	40,645.	26.	0.	0.	40,645.	26.
30	0.	0.	0.	0.	40,645.	25.	0.	0.	40,645.	25.

Appendix 12. Comparison of projected quarantined herds versus actual quarantined herds, current bovine brucellosis program, 1976-84

Model year	APHIS fiscal year	Projected quarantined herds	Actual quarantined herds	Percent deviation projected vs. actual
1	1976	15,852	16,910	-6.3
2	1977	14,731	14,332	2.8
3	1978	14,052	14,692	-4.4
4	1979	13,749	13,872	-0.9
5	1980	12,137	12,751	-4.8
6	1981	12,659	13,218	-4.2
7	1982	11,675	11,706	-0.3
8	1983	9,988	9,866	1.2
9	1984	8,467	8,449	0.2

Appendix 13. Comparison of projected quarantined cows versus actual quarantined cows, current bovine brucellosis program, 1976-84

Model year	APHIS fiscal year	Projected quarantined cows	Actual quarantined cows	Percent deviation projected vs. actual
1	1976	233,418	186,663	25.0
2	1977	182,942	161,922	13.0
3	1978	141,778	171,035	-17.1
4	1979	128,983	141,128	-8.6
5	1980	137,878	143,888	-4.2
6	1981	149,120	142,342	4.8
7	1982	139,260	124,723	11.7
8	1983	107,560	105,840	1.6
9	1984	88,756	83,059	6.9

Appendix 14. Comparison of projected on-farm tests versus actual on-farm tests, current bovine brucellosis program, 1976-84

Model year	APHIS fiscal year	Projected on-farm tests	Actual on-farm tests	Percent deviation projected vs. actual
1	1976	9,359,701	7,350,000	27.3
2	1977	8,165,627	7,270,000	12.3
3	1978	7,496,619	6,990,000	7.2
4	1979	6,941,869	6,710,000	3.5
5	1980	6,965,980	6,990,000	-0.3
6	1981	7,584,656	7,600,000	-0.2
7	1982	7,507,380	6,920,000	8.5
8	1983	6,423,371	6,240,000	2.9
9	1984	5,983,578	5,445,708	9.9

Appendix 15. Comparison of projected MCI cattle tested versus actual MCI cattle tested, current bovine brucellosis program, 1976-84

Model year	APHIS fiscal year	Projected MCI cattle tested	Actual MCI cattle tested	Percent deviation projected vs. actual
1	1976	13,528,947	15,657,074	-13.6
2	1977	13,410,233	14,150,463	-5.2
3	1978	12,795,314	14,377,108	-11.0
4	1979	10,993,468	11,359,104	-3.2
5	1980	11,558,625	11,296,791	2.3
6	1981	12,264,209	12,507,445	-1.9
7	1982	13,250,090	13,102,705	1.1
8	1983	15,093,959	15,603,713	-3.3
9	1984	15,354,022	15,233,587	0.8

Appendix 16. Comparison of projected number of official vaccinates versus actual number of official vaccinates, current bovine brucellosis program, 1976-84

Model year	APHIS fiscal year	Projected official vaccinates	Actual official vaccinates	Percent deviation projected vs. actual
1	1976	3,840,547	3,840,623	a
2	1977	3,840,547	3,757,906	2.2
3	1978	4,057,945	4,057,952	a
4	1979	5,089,389	5,089,403	a
5	1980	5,835,820	5,835,858	a
6	1981	6,868,424	6,868,416	a
7	1982	7,549,136	7,549,136	0
8	1983	7,854,161	8,070,418	-2.7
9	1984	8,819,874	8,837,746	-0.2

[a] Less than 0.005.

Appendix 17. Quarantined infected beef and dairy cows, by program, United States, 1976-2005[a]

Year	Baseline program	Current program	Realistic eradication	Theoretical eradication	Baseline-25% increase in efficiency in C regions	Baseline-25% decrease in efficiency in C regions	No program[b]	No program with 45% calfhood vaccination[b]	No program with 75% calfhood vaccination[b]
1976	207,101	207,101	207,101	207,101	207,101	207,101	207,101	207,101	207,101
	26,317	26,317	26,317	26,317	26,317	26,317	26,317	26,317	26,317
	233,418	233,418	233,418	233,418	233,418	233,418	233,418	233,418	233,418
1980	127,096	127,096	127,096	127,096	127,096	127,096	127,096	127,096	127,096
	10,782	10,782	10,782	10,782	10,782	10,782	10,782	10,782	10,782
	137,878	137,878	137,878	137,878	137,878	137,878	137,787	137,878	137,878
1985	55,373	70,662	59,926	53,208	84,410	53,677	0	0	0
	3,507	3,222	3,102	3,088	3,316	3,426	11,154	11,154	11,154
	58,880	73,884	63,028	56,296	87,726	57,103	11,154	11,154	11,154
1990	44,646	28,035	3,648	69	14,435	46,653	0	0	0
	3,010	1,791	709	78	1,127	3,044	45,413	18,533	7,999
	47,656	29,826	4,357	147	15,562	49,697	45,413	18,533	7,999
1995	53,075	21,655	1,349	6	9,180	59,939	0	0	0
	3,083	1,297	287	20	672	3,353	195,364	44,203	10,611
	56,158	22,952	1,636	26	8,852	63,292	195,364	44,203	10,611
2000	55,584	15,858	175	1	6,214	71,081	0	0	0
	3,178	1,016	117	15	485	3,800	582,903	96,961	15,664
	58,762	16,874	292	16	6,699	74,881	582,903	96,961	15,664
2005	70,008	13,875	123	0	6,290	104,115	0	0	0
	3,216	729	85	14	410	4,448	1,283,950	192,019	23,936
	73,224	14,604	208	14	6,700	108,563	1,283,950	192,019	23,936

[a]Data by year and program reflect beef, dairy and total, respectively.
[b]Quarantined dairy cows after 1984 are identified infected dairy cows.

Appendix 18. Undetected infected beef and dairy cows, by program, United States, 1976-2005[a]

Year	Baseline program	Current program	Realistic eradication	Theoretical eradication	Baseline-25% increase in efficiency in C regions	Baseline-25% increase in efficiency in C regions	No program	No program with 45% calfhood vaccination	No program with 75% calfhood vaccination
1976	130,304	130,304	130,304	130,304	130,304	130,304	130,304	130,304	130,304
	1,449	1,449	1,449	1,449	1,449	1,449	1,449	1,449	1,449
	131,753	131,753	131,753	131,753	131,753	131,753	131,753	131,753	131,753
1980	105,393	105,393	105,393	105,393	105,393	105,393	105,393	105,393	105,393
	708	708	708	708	708	708	708	708	708
	106,101	106,101	106,101	106,101	106,101	106,101	106,101	106,101	106,101
1985	59,551	49,149	38,504	2,089	40,040	61,241	138,212	138,212	138,212
	236	192	144	4	170	239	1,991	1,991	1,991
	59,787	49,341	38,648	2,093	40,210	61,480	140,203	140,203	140,203
1990	53,428	24,381	6,675	108	10,487	62,160	630,240	364,278	225,707
	161	88	28	0	56	165	8,951	3,664	1,589
	53,589	24,469	6,703	108	10,543	62,325	639,191	367,942	227,296
1995	63,823	19,568	2,569	19	6,986	85,620	2,302,638	846,370	327,270
	159	64	11	0	34	170	41,223	9,114	2,154
	63,982	19,632	2,580	19	7,020	85,790	2,343,861	855,484	329,424
2000	62,283	12,320	799	3	4,357	100,696	5,001,884	1,629,074	482,051
	152	51	5	0	24	172	129,349	20,629	3,239
	62,435	12,371	804	3	4,381	100,868	5,131,233	1,649,703	485,290
2005	78,183	10,379	455	2	4,182	151,996	8,706,496	2,913,847	750,698
	161	39	3	0	23	208	301,540	42,240	5,066
	78,344	10,418	458	2	4,205	152,204	9,008,036	2,956,087	755,764

[a]Data by year and program reflect beef, dairy and total, respectively.

Appendix 19. Total infected beef and dairy cows, by program, 1976-2005[a]

Year	Baseline program	Current program	Realistic eradication	Theoretical eradication	Baseline-25% increase in efficiency in C regions	Baseline-25% increase in efficiency in C regions	No program	No program with 45% calfhood vaccination	No program with 45% calfhood vaccination
1976	337,406	337,406	337,406	337,406	337,406	337,406	337,406	337,406	337,406
	27,766	27,766	27,766	27,766	27,766	27,766	27,766	27,766	27,766
	365,172	365,172	365,172	365,172	365,172	365,172	365,172	365,172	365,172
1980	232,489	232,489	232,489	232,489	232,489	232,489	232,489	232,489	232,489
	11,490	11,490	11,490	11,490	11,490	11,490	11,490	11,490	11,490
	243,979	243,979	243,979	243,979	243,979	243,979	243,979	243,979	243,979
1985	114,923	119,812	98,430	55,297	124,450	114,918	138,212	138,212	138,212
	3,743	3,415	3,246	3,092	3,486	3,665	13,145	13,145	13,145
	118,666	123,227	101,676	58,389	127,936	118,583	151,357	151,357	151,357
1990	98,074	52,416	10,324	177	24,922	108,813	630,240	364,278	225,707
	3,171	1,879	737	78	1,183	3,210	54,364	22,197	9,588
	101,245	54,295	11,061	255	26,105	112,023	684,604	386,475	235,295
1995	116,898	41,224	3,917	25	16,167	145,558	2,302,638	846,370	327,270
	3,242	1,362	298	20	706	3,523	236,588	53,317	12,765
	120,140	42,586	4,215	45	16,873	149,081	2,539,226	899,687	340,035
2000	117,867	28,178	975	4	10,571	171,777	5,001,884	1,629,074	482,051
	3,330	1,067	122	15	508	3,973	712,253	117,591	18,903
	121,197	29,245	1,097	19	11,079	175,750	5,714,137	1,746,665	500,954
2005	148,192	24,254	577	2	10,473	256,111	8,706,496	2,913,847	750,698
	3,378	768	88	14	433	4,656	1,585,491	243,260	29,002
	151,570	25,022	665	16	10,906	260,767	10,291,987	3,148,107	779,700

[a]Data by year and program reflect beef, dairy, and total, respectively.

Appendix 20. Beef and dairy weaner calf losses, by program, United States, 1976-2005[a]

Year	Baseline program	Current program	Realistic eradication	Theoretical eradication	Baseline-25% increase in efficiency in C regions	Baseline-25% decrease in efficiency in C regions	No program	No program with 45% calfhood vaccination	No program with 75% calfhood vaccination
					One-thousand pounds				
1976	47,029	47,029	47,029	47,029	47,029	47,029	47,029	47,029	47,029
	579	579	579	579	579	579	579	579	579
	47,608	47,608	47,608	47,608	47,608	47,608	47,608	47,608	47,608
1980	31,782	31,782	31,782	31,782	31,782	31,782	31,782	31,782	31,782
	252	252	252	252	252	252	252	252	252
	32,034	32,034	32,034	32,034	32,034	32,034	32,034	32,034	32,034
1985	15,993	16,295	13,296	6,892	16,659	16,047	22,790	22,790	22,790
	80	72	68	62	73	78	312	312	312
	16,073	16,367	13,364	6,954	16,732	16,125	23,102	23,102	23,102
1990	13,323	7,030	1,412	27	3,324	14,833	88,637	48,386	28,577
	68	40	16	2	25	69	1,234	478	197
	13,391	7,070	1,428	29	3,349	14,902	89,871	48,864	28,774
1995	15,971	5,540	548	4	2,170	19,978	319,773	111,838	40,910
	69	29	6	b	15	76	5,337	1,149	263
	16,040	5,569	554	4	2,185	20,054	325,110	112,987	41,173
2000	16,019	3,752	142	1	1,420	23,429	671,355	211,223	59,889
	71	22	3	b	11	86	16,042	2,549	394
	16,090	3,774	145	1	1,431	23,515	687,397	213,772	60,283
2005	20,519	3,275	88	b	1,427	35,535	1,171,135	382,437	94,852
	73	16	2	b	9	101	35,349	5,033	602
	20,592	3,291	90	1	1,436	35,636	1,206,484	387,470	95,454

[a]Data by year and program reflect beef, dairy, and total, respectively.
[b]Less than 500 pounds.

Appendix 21. Dairy milk losses, by program, United State, 1976-2005

Year	Baseline program	Current program	Realistic eradication	Theoretical eradication	Baseline—25% increase in efficiency in C regions	Baseline—25% decrease in efficiency in C regions	No program	No program with 45% calfhood vaccination	No program with 75% calfhood vaccination
					Hundredweight				
1976	619,193	619,193	619,193	619,193	619,193	619,193	619,193	619,193	619,193
1980	262,664	262,664	262,664	262,664	262,664	262,664	262,664	262,664	262,664
1985	87,267	80,737	77,336	75,884	82,200	85,447	293,039	293,039	293,039
1990	73,572	45,744	17,950	1,872	27,258	73,544	1,230,802	505,187	220,145
1995	74,488	33,802	7,255	422	15,913	78,832	5,320,266	1,202,901	289,916
2000	75,844	27,004	2,866	310	11,222	87,157	16,080,474	2,639,852	424,144
2005	76,099	19,235	2,124	299	9,360	100,226	35,815,037	5,301,481	650,074

2M—4-86